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REPUBLIC OF SOUTH AFRICA

RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTU/MHLATUZE WATER MANAGEMENT AREA

WP 10544

LAKE SIBAYA INTERMEDIATE EWR

VOLUME 3 – SPECIALIST REPORTS

FINAL

NOVEMBER 2015

Report No. RDM/WMA6/CON/COMP/1813

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DEPARTMENT OF WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS
CONTRACT NO. WP 10544

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This report should be cited as:

Department of Water and Sanitation (DWS). 2015. Chief Directorate – Water Ecosystems: Reserve determination study of selected surface water and groundwater resources in the Usuthu/Mhlathuze Water Management Area. Lake Sibaya EWR – Volume 3 - Specialist Reports. Produced by Tlou Consulting (Pty) Ltd and Southern Waters Ecological Research and Consulting cc. Report no: RDM/WMA6/CON/COMP/1813.

Contract Title:	Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Usuthu - Mhlathuze Water Management Area
Report Title:	Lake Sibaya EWR – Volume 3: Specialists Reports
Report compilation:	K Reinecke
Editors	A Singh & C Brown

Revision	Date	Report Status
Draft 1.1	30 Oct 2015	Draft for external comment
Final	30 Nov 2015	Final

<u>Consultants: Tlou Consulting (Pty) Ltd and Southern Waters</u>

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Dr C Brown	A Singh
Internal Reviewer	Project Manager

<u>Client: Department of Water and Sanitation</u>

Approved for the DWS:

…………………………………………..

N Mohapi

Chief Director: Water Ecosystems

ACKNOWLEDGEMENTS

The assistance of the following organisation and individuals is gratefully acknowledged:

Hydrology and Imagery

- The Department of Water and Sanitation, specifically Bryan Pillay, Mark Kempen Nirdosh Punchum, Atish Rajkoomar, Vikash Singh and Natasha Mangaroo for providing water level data and information on the Lake Sibaya gauging station.
- Molla Demlie for providing various information.
- US Geological Survey Earth Explorer for satellite imagery.
- The South African National Space Agency (Earth Observation), specifically Nomnikelo Bongoza for satellite imagery.

Fish

The assistance of Mr Molefi Mazibuko of the Department of Water and Sanitation is acknowledged, with gratitude.

Birds

The Avian Demography Unit, University of Cape Town for supply of CWAC (bird) data.

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ABBREVIATIONS AND ACRONYMS

AEC	Alternative Ecological Category
amsl	above mean sea level
BHN	Basic Human Needs
Cl	Chloride
CPUE	Catch per unit effort
CSIR	Council for Scientific and Industrial Research
CRS	Coordinate reference system
CWAC	Coordinated Wetland Counts
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphate
DO	Dissolved oxygen
DRIFT	Downstream Response to Imposed Flow Transformation
DSF	Desired Future Status
DSS	Decision Support System
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EC	Ecological Category/Electrical Conductivity
EIS	Ecological Importance and Sensitivity
EKZNW	Ezemvelo KZN Wildlife
EMC	Ecological Management Class
ERC	Ecological Reserve Category
EWR	Ecological Water Requirements
GE	Google Earth
GIS	Geographical Information System
IFR	Instream Flow Requirement
LWR	Lake Water Requirement Approach
Mg/l	Milligrams per litre
msl	Mean sea level
mS/m	Millisiemens per litre
NaCl	Sodium Chloride
NGI	National Geo-spatial information
PES	Present Ecological State
REC	Recommended Ecological Condition
TC	Total Carbon
TN	Total Nitrogen
TP	Total Phosphorous
UNEP	United Nations Environmental Programme
VEGRAI	Riparian Vegetation and Assessment Index
WMA	Water Management Area

WQ	Water Quality

GLOSSARY OF TERMS

Bathymetry	The measurement of depth of water in oceans, seas, or lakes.
Ecological Categories	A distinction is made between Management Classes, which form part of the National Classification System, and Ecological Categories, which forms part of the Ecological Water Requirement assessment.
Ecological Category (EC)	replaces former terms used, namely: Ecological Reserve Category (ERC), Desired Future State (DFS) and Ecological Management Class (EMC).
Ecological Water Requirements (EWR)	should be used instead of the term Instream Flow Requirements (IFR) for various reasons, including international acceptance of the former term.
Ecosystem Integrity	refers to the integrated composition of physicochemical, habitat and biotic characteristics on a temporal and spatial scale that are comparable to the characteristics of natural ecosystems of the region.
Geoxylic suffrutex	a plant with annual or short lived woody above ground shoots sprouting from a massive or extensive perennial underground stem.
Neophyte:	a plant species recently introduced into an area.
Photic zone:	extends from the water's surface down to a depth where light intensity falls to one percent of that at the surface, also called the euphotic depth or sunlight zone.
Phreatophyte	plants with temporary or permanent access to groundwater.
Preliminary Reserve	refers to Reserve signed off by the Minister or her representative in the absence of the Classification Process having been undertaken in the basin.
Profundal zone	A deep zone of an inland body of freestanding water, such as a lake or pond, located below the range of effective light penetration.
Recommended Ecological Condition (REC)	the target maintenance Ecological Condition for a water resource based solely on ecological criteria.
Reserve	refers to the EWR for maintaining a particular ecological condition where operational limitations and stakeholder consultation are taken into account. The Reserve includes both ecological and Basic Human Needs (BHN) requirements.
Stage	refers to the water level in a river or stream with respect to a chosen reference height.

Suffrutex	low growing woody shrub or perennial with woody base.

1 INTRODUCTION

1.1 Background to the study

The Chief Directorate: Water Ecosystems of the Department of Water and Sanitation (DWS), issued an open tender invitation for the "*Appointment of a Professional Service Provider to undertake Reserve Determinations for selected Surface water, Groundwater, Estuaries and Wetlands in the Usuthu to Mhlatuze Basins*". The focus on this area was a result of the high conservation status and importance of various water resources in the basin and the significant development pressures affecting the availability of water in the area.

Reserve determinations are required to assist the DWS in making informed decisions with respect to the magnitude of the impacts of the proposed developments on the water resources in the Water management Area (WMA), and to provide the input data for Water Resource Classification of the area, and eventual gazetting of the Reserve (DWAF 1999a).

In July 2013, DWS appointed Tlou Consulting to undertake the project.

1.1.1 Study objectives

The objectives of the overall study are to:

- determine the Ecological Reserve (DWAF 1999a) at various levels of detail, for the Nyoni, Matigulu, Mlalazi, Mhlatuze, Mfolozi, Nyalazi, Hluhluwe, Mzinene, Mkuze, Assegaai and Pongola Rivers;
- determine the Ecological Reserve, at an Intermediate level, for the Pongola Floodplain;
- determine the Ecological Reserve, at an Intermediate level, for the St Lucia/Mfolozi, Estuary System;
- determine the Ecological Reserve, at a Rapid level, for the Mlalazi Estuary;
- determine the Ecological Reserve, at a Rapid level, for the Amatikulu Estuary;
- determine the Ecological Reserve, at an Intermediate level, for Lake Sibaya;
- determine the Ecological Reserve, at a Rapid level for Kozi Lake and Estuary;
- classify the causal links between water supply and condition of key wetlands;
- incorporate existing EWR assessments on the Mhlatuze (river and estuary) and Nhlabane (lake and estuary) into study outputs;
- determine the groundwater contribution to the Ecological Reserve, with particular reference to the wetlands;
- determine the Basic Human Needs Reserve for the Usuthu/Mhlatuze WMA;
- outline the socio-economic water use in the Usuthu/Mhlatuze WMA;
- build the capacity of team members and stakeholders with respect to EWR determinations and the ecological Reserve.

1.2 This report

This report is Volume 3 of four volumes of the Lake Sibaya Intermediate EWR Report:

Volume 1: EcoClassification Report
Volume 2: EWR Assessment – Results
Volume 3: Specialist reports
Volume 4: EcoSpecs and Monitoring Programme.

1.3 The Study Area

Lake Sibaya is located in the northern part of the Mkuze region of the Usutu Mhlatuze catchment near the coast Figure 1.1.

For the purposes of this study Lake Sibaya was subdivided into five EWR zones, the: Main Basin, Northern Arm, Western Arm, South-western Basin and Southern Basin (Figure 1.2).

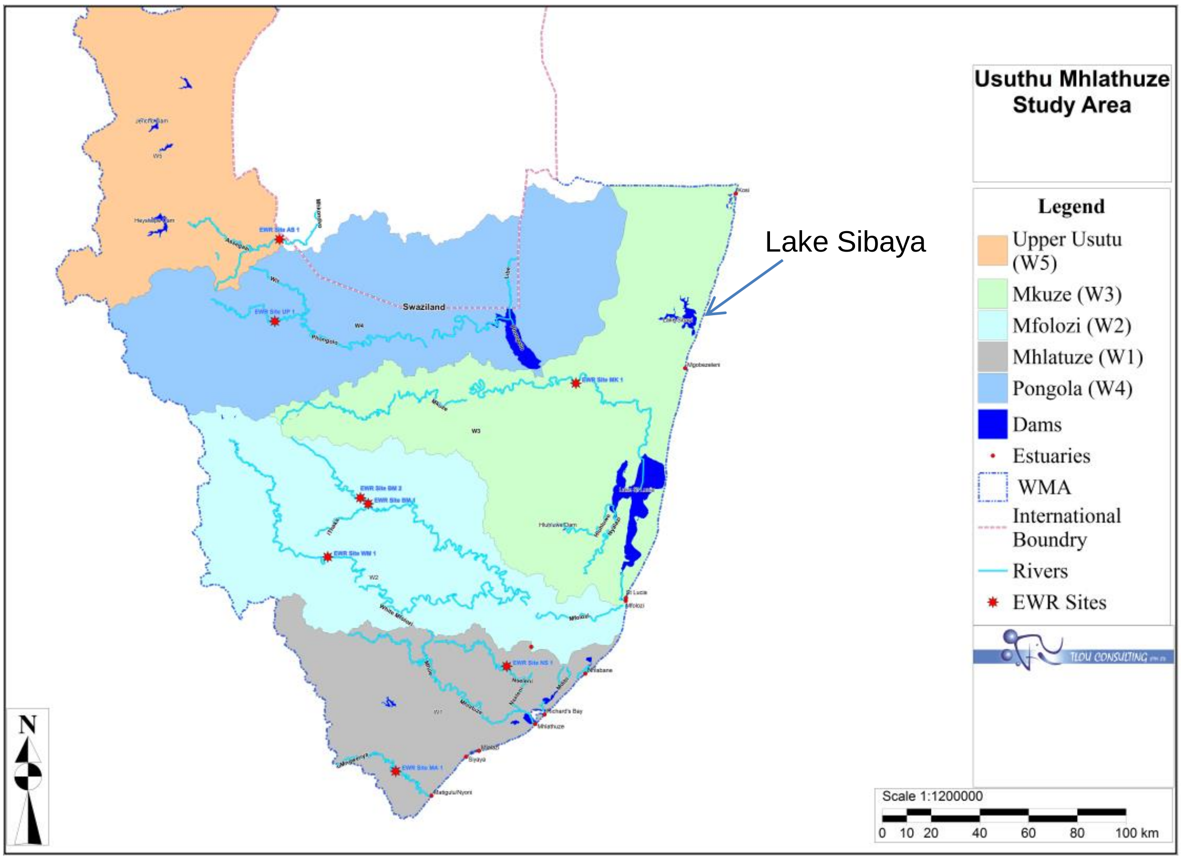

Figure 1.1 Location of Lake Sibaya in Usutu Mhlatuze catchment, showing the EWR river sites

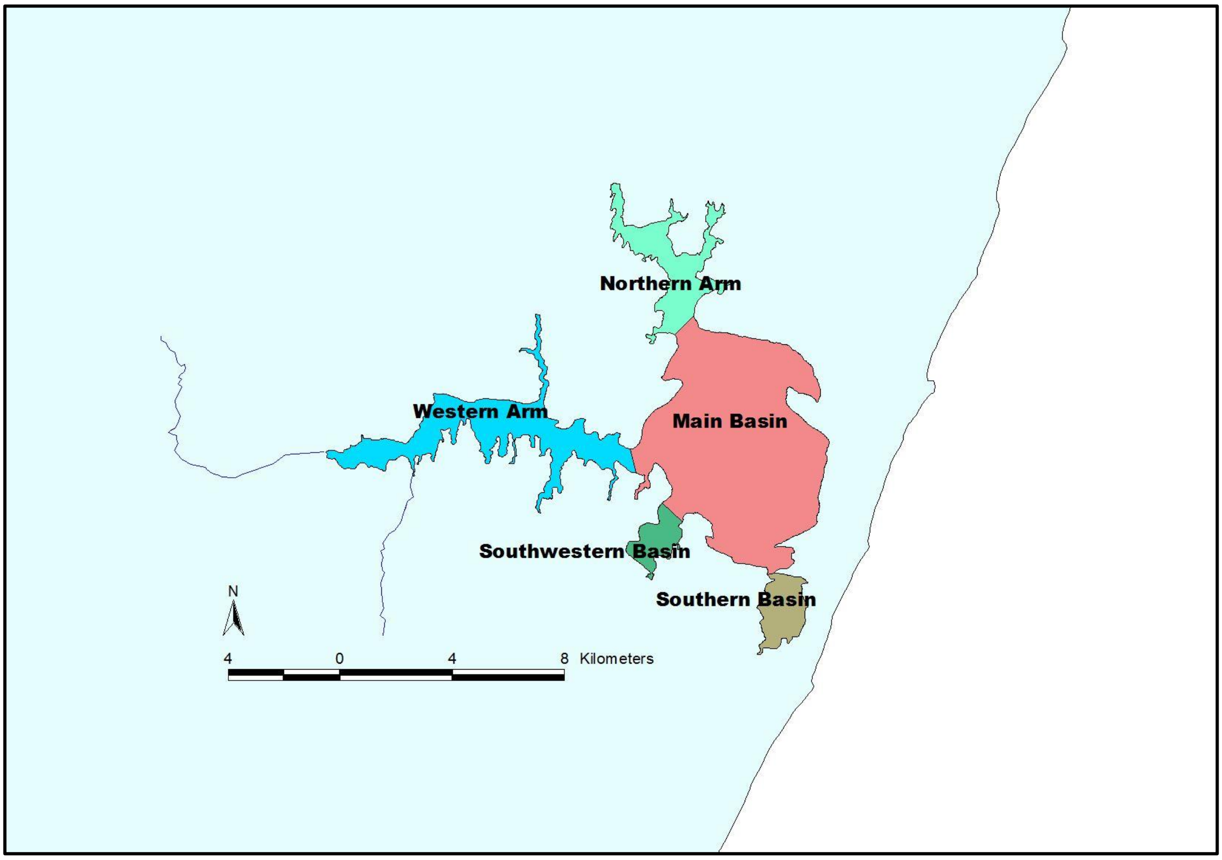

Figure 1.2 The five main EWR zones of the lake

1.4 Specialist Team

The specialist team responsible for the contents of this report are listed in Table 1.1.

Table 1.1 Study team specialists

Name	Affiliation	Role
Drew Birkhead	Streamflow Solutions	Hydraulics
Susan Taljaard	CSIR	Water quality
James MacKenzie	BioRiver Solutions	Vegetation
Ricky Taylor	Hydrological Training and Research Specialists	Herpetofauna, semi-aquatic mammals, molluscs and macrocrustacea
Steven Weerts	CSIR	Icthyofauna
Jane Turpie	Anchor Environmental	Avifauna
Toriso Tlou	Tlou Consulting	Social

2 HYDRAULICS

2.1 Objective

The objective of this component of the Ecological Water Requirement (EWR) study for Lake Sibaya was to provide so-called[1] “hydraulic” indicators for use in the DRIFT DSS (Downstream Response to Informed Flow Transformation Decision Support System). This is discussed in this chapter with reference to the available data, construction of the Lake Sibaya Digital Elevation Model (DEM) and computation of indicators for use in the DRIFT DSS.

2.2 Data

2.2.1 Historically monitored water levels at Lake Sibaya

Water level data are available for the DWS Gauging Station W7R001 located in the Southwestern zone of the Southern Basin (Figure 2.1), and were obtained from the Hydrological Services of the DWS as daily averages. The data cover the period October 1967 to May 2015. For the period preceding October 1980 there were differences in the data: one of the records were supplied as local gauge levels in the range 0.87 m to 4.53 m; the other record increases (linearly) over the 13-year period from an ostensible gauge level of 3.58 m to a stage of 18.91 m relative to mean sea level (msl) in 1980. This suggests there have been changes to the gauge datum used for this station over the 48-year measurement period, and these have not been resolved. Also, since July 2012 (and possibly including April/May 2008), peaks exist in the gauge record displaying rapid rates of rise and fall that do not appear previously. For this latter period from May 2008 to July 2015, 93 manual readings[2] of the gauge plates were obtained. These are deemed to provide a more reasonable reflection of recent water level behaviour, and have been interpolated to provide monthly data for the last seven years. This record gives a stage reading of 15.43 m for June 2015, which compares more favourably with a manually surveyed level of 15.77 m for the Main Basin and 14.47 m for the Southern Basin observed in July 2015 during a site visit for this project.

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[1] since the indicators are hydrostatic in nature, and for the remainder of this chapter and merely termed “indicators”

[2] done at the time of station inspection and logger data retrieval

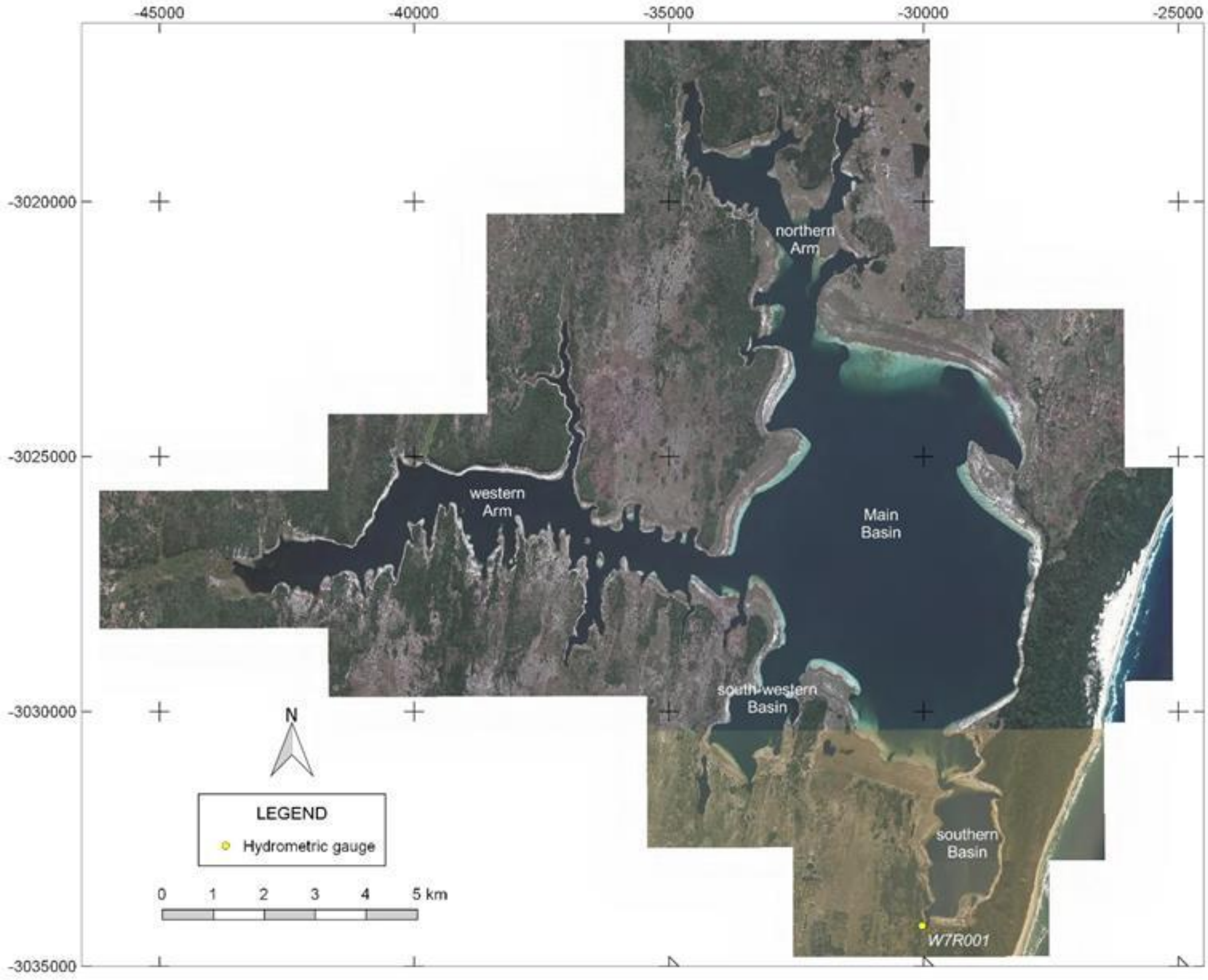

Figure 2.1 **Tiled satellite images (Google Earth 2013) of Lake Sibaya, showing the sub-division of the Lake into five EWR zones , and the location of DWS Gauging Station W7R001 at the south-west corner of the Southern Basin (Coordinate Reference System (CRS) used is Hartebeeshoek Lo33°)**

The reason for the 1.3-m water level difference between the Southern and Main Basins is that these two basins have become disconnected and now have a water level diference of c. 1.3m. To this end, Station W7R001 has for some time not been recording Main Basin levels.[3] For this study, there is insufficient information available to distinguish long-term difference in the water levels in the Southern and Main[4] Basins, and so they have been treated as the same. One of the two DWS daily records has an (ostensibly gauge plate) reading of 3.87 m on 17 September 1980, and an (ostensibly stage relative to msl) reading two days later of 18.92m. Given that very low rates of change can be expected in the lake over two days in the dry season, it is reasonable to apply an offset value of 16.11 m (18.92 m - 3.87 m) to the former gauge plate record so that it is expressed relative to msl.

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[3] Hydrological Services (DWS) were made aware of this.

[4] and its other appendages

Further justification for this has been provided from comparative analyses of aerial photographs as reported in Volume 2, the EWR Results report which shows that the resultant water level appear to be correct. The monthly historical records of the lake stages (see Section 2.6, Table 2.1) used in this study are plotted in Figure 2.2 for the period July 1968 to May 2015.[5] It is important to note that the msl datum used in this study for lake stages and the related[6] lake topography is in accordance with that provided for Station W7R001 by the Hydrological Services of the DWS.

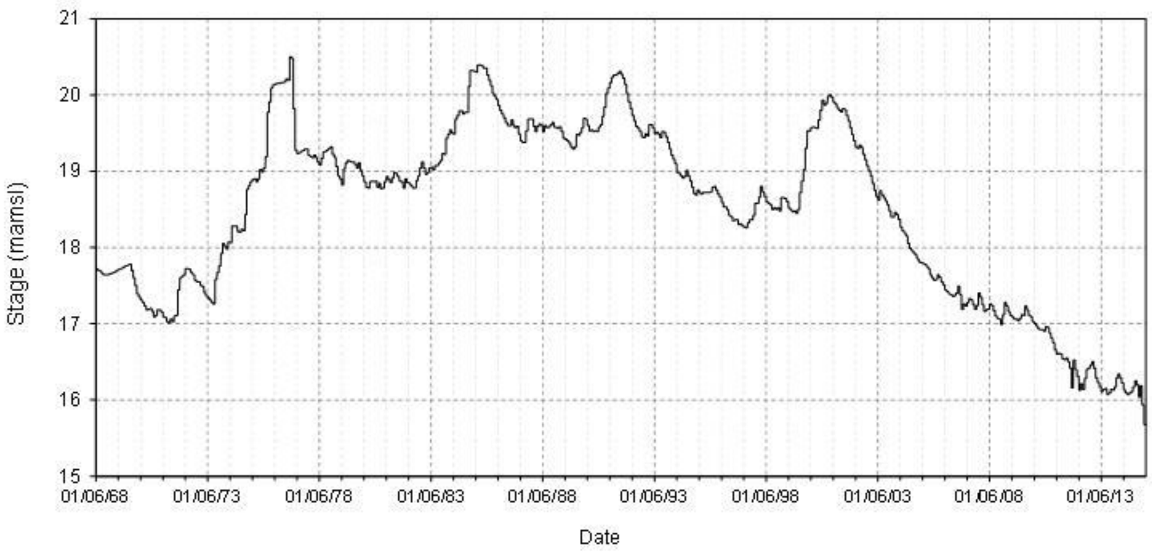

Figure 2.2 **Monitored 47-year monthly stage record from June 1968 to May 2015 for DWS Gauging Station W7R001 at Lake Sibaya**

2.2.2 Topographic and bathymetric data

The following topographic information was obtained for Lake Sibaya:

- bathymetric data from a sonar survey carried out between May 1992 and August 1993 (Miller 1998);
- and the national 25m Digital Elevation Model (DEM)[7] available from National Geo-spatial Information (NGI) (Department of Rural Development and Reform)[8]. The standard error of the DEM is quoted as 1.2 m[9] and 2.5 m in flatter areas (NGI 2011).

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[5] These data are provided in the Appendix.

[6] since bathymetric survey data have been provided relative to water surface at the time of survey (refer to Section 2.2.2)

[7] In this study,DEM is synonymous with Digital Terrain Model (DTM). Since the DEM is obtained photogrammetrically, the extent to which it represents a Digital Surface Model (DSM) which includes features such as vegetation, is unclear.

[8] http://www.ngi.gov.za/

[9] σ (one standard deviation)

2.3 Construction of the Lake Sibaya Digital Elevation Model

The bathymetric data included "water edge" locations (zero depths) that were manually digitised from a Google Earth (GE) image[10], and represented the outer boundary or "mask" for the surveyed bathymetry. These edges were removed from the dataset. The average stage over the duration of the bathymetric survey was 19.56 m (Figure 2.2) and was used as the reference level to compute reduced bottom levels for the lake. Available satellite multi-spectral imagery (Landsat and Spot 5) data were assessed for stages corresponding as closely as possible to 19.56 m, when the above survey was carried out. Landsat 7 imagery for 1st July 2001, with a stage of 19.88 m, was selected for the bathymetric data mask, and sonar observations were interpolated using a 25 m grid.[11] The lake topography above this level is important for the EWR assessment (the highest recorded average monthly stage is 0.62 m higher at 20.50 m for February 1977, Figure 2.2)[12]. The national 25 m DEM was used to extend the bathymetrically-determined lake topography.[13] The locations of tree-lines, as indicated in Figure 2.3, are clearly visible on the high resolution (GE 2014) satellite imagery.

The tree elevations were manually surveyed (relative to the lake stage, in July 2015) at a few sites around the lake, and these were compared with elevations from the 25 m national DEM. Based on this, the (national) DEM (surrounding the lake) was increased by 1.0 m, and has been used to extend the bathymetric DEM to 22.0 m. The final DEM for Lake Sibaya is illustrated in Figure 2.4.

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[10] ostensibly the earliest available image dated January 2006, which corresponds to a stage of 17.58m

[11] The projected Hartebeeshoek Lo33° Coordinate Reference System (CRS) was used, with a grid spacing of 25m.

[12] 20.64m on 28 February and rising, with missing data thereafter

[13] Although of reduced accuracy, this appears to be the best available data source to extend the bathymetric DEM.

Figure 2.3 Clearly-defined tree-line along the western side of the Main Basin, north of its connection to the Western Arm (GE, 25/12/2014)

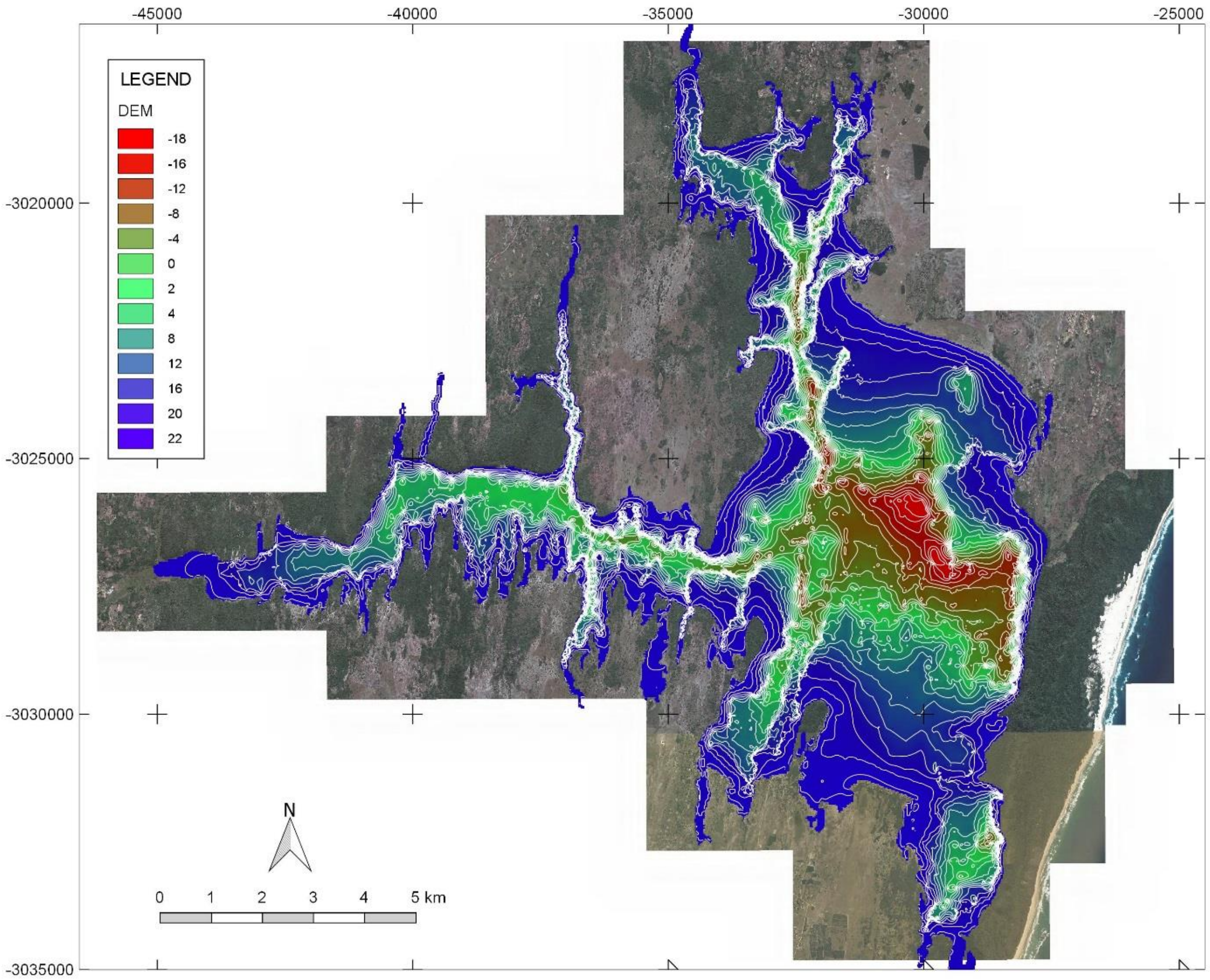

Figure 2.4 **Digital Elevation Model of Lake Sibaya with superimposed contours at 2m intervals over the range -18.0m to 22.0m (Coordinate Reference System (CRS) used is Hartebeeshoek Lo33°)**

2.4 Computation of indicators for use in the DRIFT DSS

The DEM (as plotted in Figure 2.4) provided the basis for computing hydrostatic indicators for use in the DRIFT DSS. The gridded ordinates (137,212 points constitute the DEM) were categorized according to the five lake zones (refer to Figure 1.2), and for each zone, stage *versus* surface area, volume and perimeter were calculated. Further post-processing software was developed to facilitate the calculation of additional indicators (or parameters). These indicators may be expressed using units of either inundated surface area (in km^2); storage volume (in million m^3); wetted perimeter or length of waters edge around the lake (in km); vertical distance (m); or horizontal distance (m). The indicators themselves are defined by lower and upper depth ranges, which may both be relative to stage (*eg.*, for fish, four depth[14] classes were required up to 2.5 m); or with one value fixed relative to msl (*eg.*, for vegetation, the vertical distance between the highest recorded stage after 1980 (20.3 mamsl[15]) and the water level was one of the habitat indicators used; for reptiles, the average horizontal distance of the exposed beach between 20.3 mamsl and the waters edge was relevant). Such indicators are defined for each of the ecological component/s (*viz.* fish; vegetation; herpetology, crustacea and molluscs; reptiles and semi-aquatic mammals; birds; water quality and) and social aspects, and calculated for each of the five lake zones.

A total of 21 indicators were computed and used in the DRIFT-DSS assessment. These were converted from stage-parameter tables to parameter time series for all water-level scenarios assessed (see Volume 2: EWR assessment report). These were imported into DRIFT as external indicators, an excerpt of which is illustrated in Table 2.2 below.

2.5 Assumptions and Limitations

The limitations and assumptions related to lake water levels, bathymetry and DEM are described in Section 2.2 and 2.3, and are not repeated here.

2.6 Raw data

2.6.1 Monitored (with corrections – refer to Section 2.2.1) stages at Lake Sibaya

Table 2.1 Average monthly stages (amsl) for Lake Sibaya for the period October 1967 to June 2015 (Month 1 = January)

Year	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1967										19.10	18.14	18.13
1968	18.00	17.90	17.89	18.81	17.73	17.72	17.70	17.69	17.66	17.64	17.64	17.64
1969	17.65	17.66	17.67	17.68	17.70	17.71	17.72	17.73	17.75	17.76	17.77	17.78
1970	17.70	17.60	17.50	17.39	17.35	17.31	17.28	17.23	17.18	17.19	17.20	17.16
1971	17.09	17.11	17.18	17.18	17.15	17.09	17.08	17.03	17.01	17.06	17.03	17.10
1972	17.11	17.44	17.60	17.62	17.64	17.72	17.72	17.71	17.67	17.64	17.57	17.55
1973	17.55	17.50	17.49	17.41	17.37	17.34	17.31	17.28	17.26	17.58	17.67	17.76
1974	17.92	18.05	18.02	17.98	18.07	18.06	18.28	18.28	18.28	18.21	18.20	18.24
1975	18.22	18.43	18.76	18.81	18.86	18.89	18.90	18.86	18.90	19.02	18.99	19.04
1976	19.19	19.77	19.91	20.09	20.13	20.14	20.15	20.15	20.16	20.16	20.17	20.21
1977	20.19	20.50	20.48	19.82	19.28	19.23	19.24	19.26	19.27	19.29	19.29	19.21
1978	19.19	19.18	19.21	19.18	19.12	19.08	19.17	19.25	19.26	19.28	19.30	19.32
1979	19.22	19.18	19.06	18.94	18.90	18.82	19.03	19.11	19.14	19.13	19.12	19.12
1980	19.09	19.04	19.11	19.01	18.94	18.86	18.79	18.78	18.86	18.87	18.86	18.87
1981	18.79	18.84	18.77	18.78	18.86	18.93	18.89	18.85	18.91	18.98	18.97	18.93

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[14] where depth is defined by a vertical height below stage.
[15] *ie*., a fixed elevation

Year	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1982	18.87	18.86	18.78	18.90	18.85	18.84	18.81	18.78	18.78	18.88	18.94	19.04
1983	19.12	19.04	18.96	18.98	19.04	19.05	19.02	19.07	19.07	19.11	19.14	19.23
1984	19.22	19.43	19.48	19.54	19.50	19.49	19.68	19.73	19.79	19.79	19.75	19.77
1985	19.77	20.11	20.32	20.32	20.31	20.30	20.39	20.39	20.38	20.35	20.35	20.26
1986	20.19	20.12	20.02	19.98	19.94	19.86	19.80	19.75	19.70	19.64	19.60	19.60
1987	19.67	19.60	19.57	19.59	19.49	19.40	19.38	19.38	19.53	19.68	19.68	19.68
1988	19.59	19.52	19.59	19.62	19.60	19.52	19.60	19.57	19.58	19.61	19.64	19.58
1989	19.57	19.56	19.58	19.52	19.43	19.42	19.40	19.37	19.32	19.29	19.32	19.48
1990	19.47	19.51	19.57	19.69	19.68	19.60	19.53	19.54	19.52	19.53	19.52	19.58
1991	19.61	19.72	19.84	20.02	20.09	20.16	20.23	20.26	20.26	20.28	20.31	20.27
1992	20.22	20.14	20.02	19.91	19.82	19.73	19.66	19.59	19.56	19.52	19.45	19.44
1993	19.49	19.46	19.61	19.61	19.57	19.49	19.51	19.49	19.44	19.52	19.51	19.45
1994	19.38	19.29	19.21	19.16	19.10	18.98	18.97	18.94	18.91	18.93	19.01	18.94
1995	18.87	18.79	18.71	18.69	18.75	18.72	18.70	18.72	18.72	18.72	18.72	18.73
1996	18.79	18.80	18.75	18.70	18.66	18.59	18.53	18.53	18.49	18.42	18.40	18.35
1997	18.36	18.36	18.30	18.31	18.28	18.27	18.26	18.32	18.36	18.36	18.42	18.58
1998	18.58	18.66	18.80	18.73	18.67	18.60	18.58	18.56	18.50	18.52	18.50	18.52
1999	18.48	18.65	18.65	18.64	18.60	18.52	18.49	18.47	18.48	18.45	18.50	18.72
2000	18.87	19.02	19.30	19.53	19.53	19.57	19.58	19.57	19.56	19.67	19.80	19.93
2001	19.87	19.89	19.98	20.00	19.97	19.91	19.88	19.83	19.80	19.78	19.82	19.81
2002	19.73	19.66	19.57	19.48	19.40	19.32	19.30	19.34	19.31	19.22	19.15	19.07
2003	19.01	18.94	18.84	18.75	18.67	18.62	18.74	18.69	18.65	18.61	18.56	18.48
2004	18.40	18.40	18.46	18.43	18.37	18.27	18.22	18.19	18.15	18.05	17.99	17.96
2005	17.93	17.90	17.85	17.81	17.80	17.79	17.78	17.75	17.72	17.64	17.60	17.57
2006	17.58	17.64	17.61	17.55	17.51	17.44	17.42	17.39	17.38	17.36	17.37	17.40
2007	17.49	17.38	17.19	17.26	17.23	17.28	17.33	17.31	17.25	17.19	17.24	17.40
2008	17.35	17.25	17.16	17.18	17.19	17.26	17.24	17.17	17.10	17.07	17.06	16.99
2009	17.12	17.28	17.23	17.16	17.11	17.09	17.06	17.06	17.04	17.07	17.12	17.11
2010	17.23	17.18	17.11	17.09	17.03	17.00	16.97	16.93	16.92	16.92	16.90	16.96
2011	16.95	16.88	16.81	16.75	16.66	16.60	16.61	16.60	16.54	16.53	16.55	16.50
2012	16.42	16.16	16.52	16.40	16.31	16.13	16.21	16.14	16.28	16.40	16.42	16.46
2013	16.50	16.42	16.29	16.23	16.17	16.11	16.14	16.15	16.07	16.09	16.14	16.13
2014	16.17	16.29	16.34	16.29	16.22	16.13	16.09	16.07	16.09	16.11	16.17	16.25
2015	16.20	16.04	16.19	15.94	15.68	15.43						

2.6.2 Example of DEM-processed result file for subsequent analyses in the DRIFT DSS

Table 2.2 External (comma delimited) file of indicators for the Main Basin and "Base" Scenario (extract from the time series for the first 7 months (June – December 1968)

```
Variable, 22
Date,Vol,Area,Perim,ExpArea,Area-7+0,Area-0.65+0.3,Area+0.6+3.8,Area+4.8+8.8,VDist+0+20.3msl,Area-7-22.9msl,Area-1-1.8,Area-2-5,Area-1.5-2,Area-1-1.5,Area-0.5-1,Area+0-0.5,Area+0-0.3,HDist+0+20.3msl,MaxDepth,Vol+0-2,Vol-2-22.9msl,Rate
1968/06/01 12:00,472.06,35.13,37.15,4.8,12.14,1.8,6.31,0,2.58,22.99,1.76,4.97,0.97,1.14,1.2,0.95,0.54,153.8,40.62,4.25,467.82,-0.052
1968/07/01 12:00,471.36,35.1,37.29,4.83,12.14,1.82,6.33,0,2.6,22.96,1.75,4.97,0.96,1.13,1.21,0.96,0.55,155,40.6,4.23,467.13,-0.052
1968/08/01 12:00,471.01,35.08,37.36,4.85,12.13,1.83,6.33,0,2.61,22.95,1.74,4.98,0.95,1.13,1.21,0.97,0.55,155.4,40.59,4.22,466.79,-0.052
1968/09/01 12:00,469.96,35.03,37.57,4.9,12.12,1.85,6.34,0,2.64,22.91,1.73,4.98,0.93,1.13,1.21,0.99,0.56,156.6,40.56,4.18,465.78,-0.052
1968/10/01 12:00,469.26,35,37.71,4.93,12.11,1.86,6.35,0,2.66,22.89,1.71,4.98,0.92,1.12,1.21,1,0.57,157.4,40.54,4.16,465.1,-0.052
1968/11/01 12:00,469.26,35,37.71,4.93,12.11,1.86,6.35,0,2.66,22.89,1.71,4.98,0.92,1.12,1.21,1,0.57,157.4,40.54,4.16,465.1,-0.052
1968/12/01 12:00,469.26,35,37.71,4.93,12.11,1.86,6.35,0,2.66,22.89,1.71,4.98,0.92,1.12,1.21,1,0.57,157.4,40.54,4.16,465.1,-0.052
```

etc.

2.7 References

NGI, 2011. Standard for Digital Elevation Model Data. Chief Directorate National Geo-spatial Information, Department of Rural Development and Land Reform. Doc. ref. QLAS.SD.3_v1. 14 pp.

3 WATER QUALITY

3.1 Introduction

This section comprises the summary report for water quality, and provides:

- Overview of the study area, in relation to water quality.
- Literature review and assessment of available data.
- Summary of data for application in EcoClassification and response curves.
- EcoClassification assessments for water quality, with supporting evidence.
- The WQ EWR at the Intermediate level for the EWR sites:
    - the DRIFT indicators chosen, and reasons therefore; and
    - the relationships between the chosen indicators and flow or other, with referenced, supporting motivations.
- EcoSpecs and monitoring programme required to describe and monitor the recommended Ecological Status with respect to water quality.

3.2 Description of the study area and EWR sites in relation to water quality

The water quality component of this study used the 5 EWR zones of Lake Sibaya as defined for the study (Figure 1.2).

The water quality at most of the EWR zones has not been impacted severely and remains in a near pristine condition. However, increased forestry and rural development, especially along the Western Arm and Southern Basin, has influenced water quality in these parts of the basin.

3.3 Literature review and assessment of available data

Detailed historical water quality data from Lake Sibaya comprises data collected from 1967 to 1979 (temperature, anions/cations, pH, dissolved oxygen and inorganic nutrients) when the Institute for Freshwater Studies (at Rhodes University) ran a research station near the lake shore (Allanson 1979). In addition, long-term water quality monitoring has been conducted in the Southern Basin by the Department of Water and Sanitation (DWS, Station W7R1 – Figure 3.1) from 1980 to 2014 (electrical conductivity, pH, anions/cations and inorganic nutrients). For this study, additional water quality data for the lake was obtained from 14 to16th July 2015 for electrical conductivity, anions/cations, pH, dissolved oxygen, turbidity, and inorganic nutrients at the stations indicated in Figure 3.1.

Figure 3.1 **Location of the DWS sampling station in the Southern Basin (W7R1) and stations sampled in July 2015 (Source: Google Earth)**

A summary of the historical water quality data, and data collected during this study, are provided below.

3.3.1 Temperature

Allanson (1979) studied the temperature regime of Lake Sibaya in detail (Figure 3.2).

As expected the lake temperature displays a strong seasonal signal with a low winter temperature (18ºC) and a high summer temperature (28ºC).

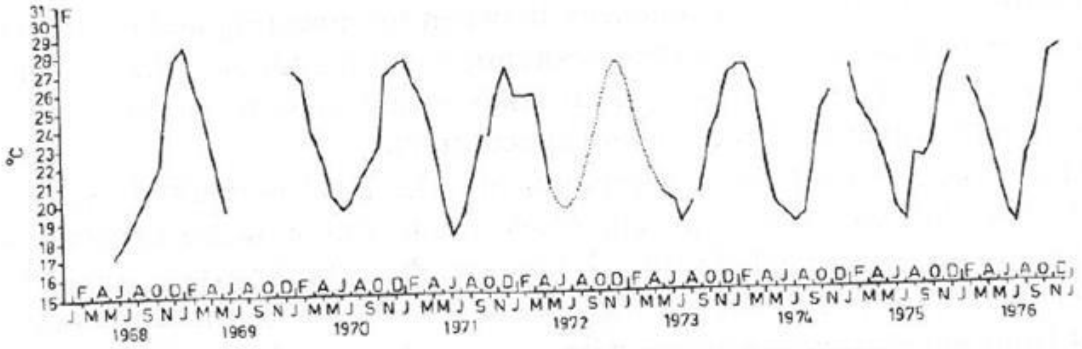


Figure 3.2 Mean monthly temperature variation in Lake Sibaya (Allanson 1979)

Despite the depth of the Main Basin (~40 m in places) there are no persistent thermoclines in the system. Limited vertical stratification has occurred at times (usually during summer) as a result of atmospheric conditions but effective wind mixing has prevented the phenomenon persisting throughout the year (Figure 3.3).

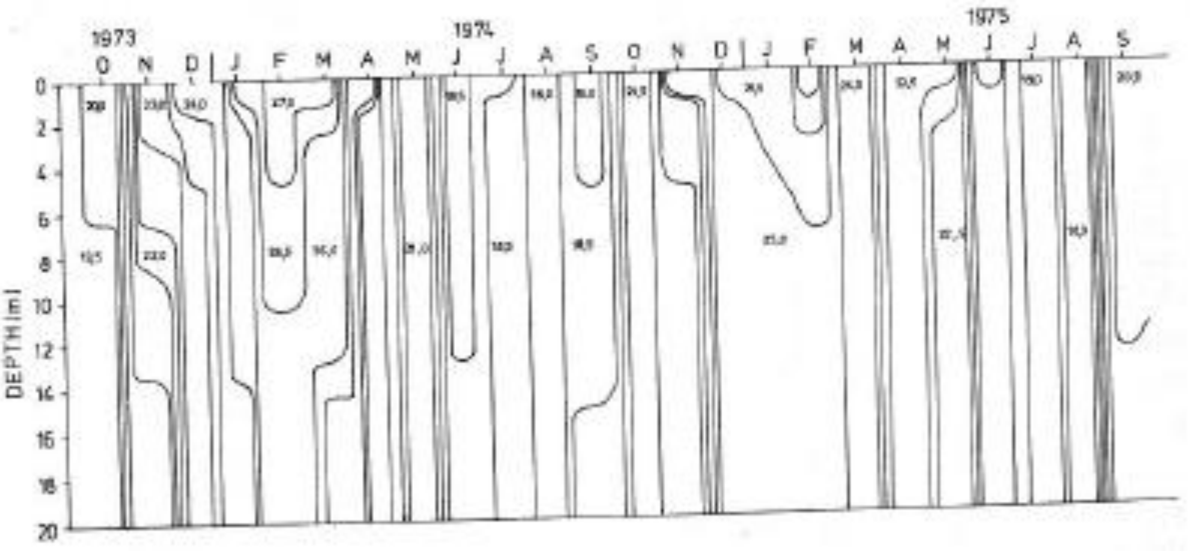


Figure 3.3 Temperature-time profiles measured in Lake Sibaya illustrating the short-lived nature of vertical stratification (Allanson 1979)

3.3.2 Electrical conductivity

Average annual electrical conductivity (EC) measured in the Southern Basin between 1980 and 2014 ranged between 54 and 73 mS/m (Figure 3.4). Similar values of EC were recorded by Allanson (1979) and ranged between 598 - 700 µmhos (assumed to be 59.8 - 70.0 mS/m).

From 2001 to 2014, EC gradually increased in the lake as a result of a continuous drop in water level, from 20 mamsl to just over 16 mamsl, most likely the influence of lower inflow and the effect of evaporation that concentrates salt levels. This produced a strong inverse, linear relationship ($r^2 = 0.7$) with water level over time (Figure 3.5). Prior to 2001, the lake level oscillated between 18 and 20 mamsl apart from a decline to 17mamsl in 1971/2.

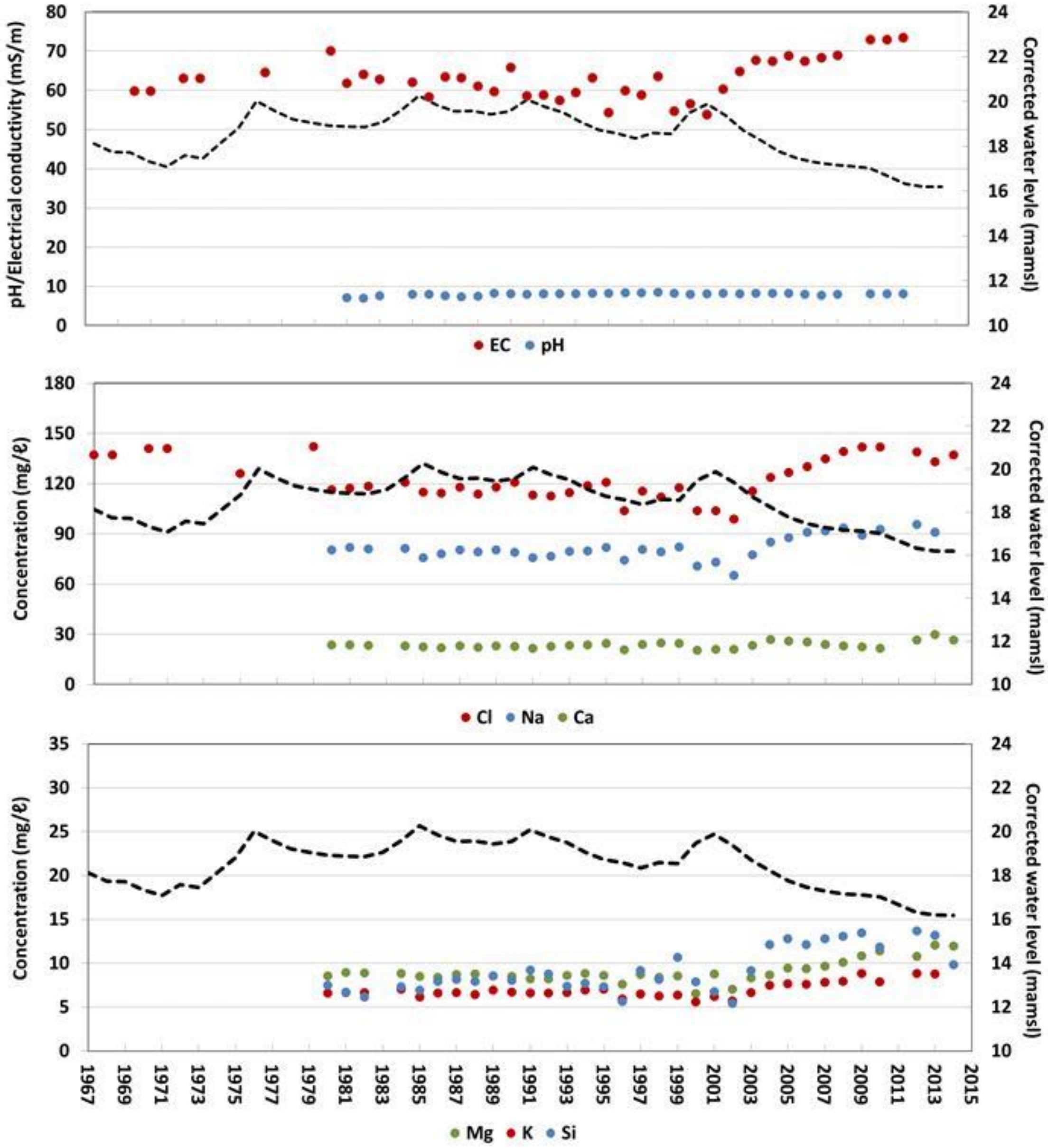


Figure 3.4 **Average annual water level and concentrations (EC, anion/cations) and annual median pH measured in the Southern Basin (W7R1, 1980-2014, DWS). EC and Cl levels prior to 1980 were recorded by Allanson (1979)**

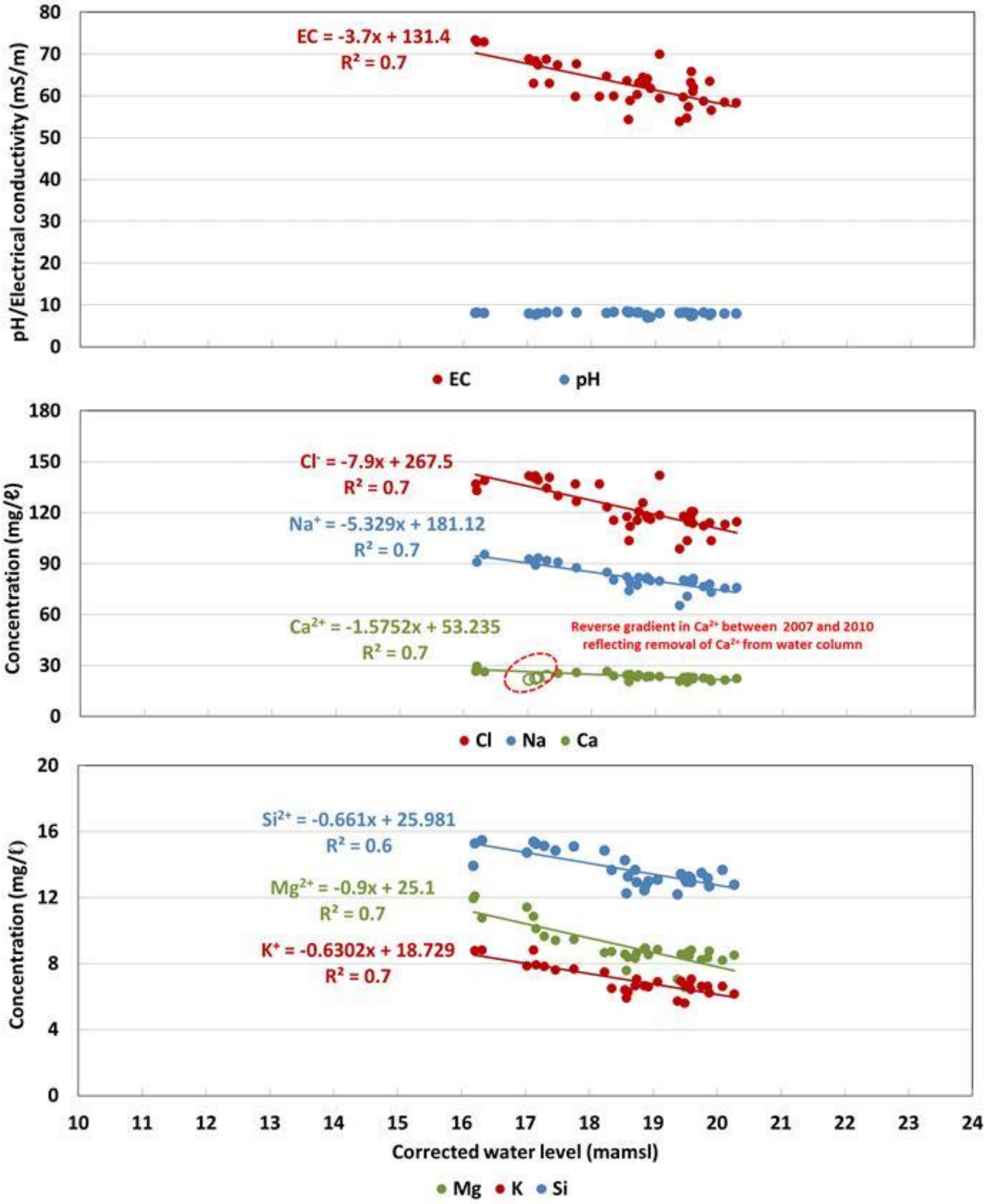


Figure 3.5 Relationship between corrected water level and average annual concentrations (EC, anion/cations) and median annual pH in the Southern Basin (W7R1, 1980-2014, DWS) and earlier studies (1967-1979) for EC and Cl (Allanson 1979)

The data collected during this study (July 2015) are summarised in Figure 3.6 (raw data in section 3.9). EC was within the ranges previously measured in the lake.

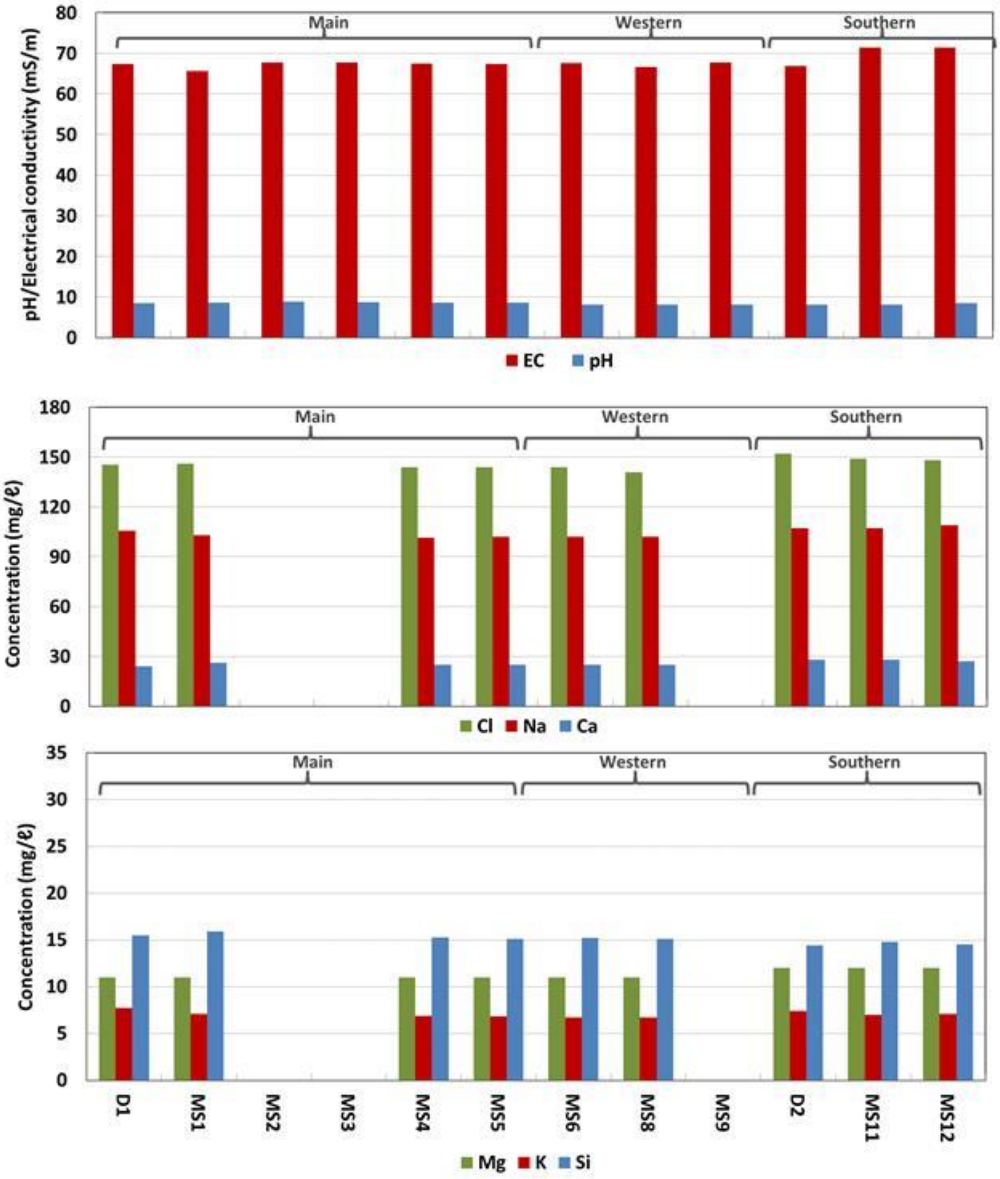


Figure 3.6 **Electrical conductivity, pH and selected cations/anions during 14-16 July 2015**

3.3.3 Major Cations and Anions

Average annual concentrations of selected cations (Ca, Na, K, Mg) and an anion chloride (Cl) measured in the Southern Basin from 1980 - 2014 are shown in Figure 3.4 above. Chloride (Cl) data prior to 1980 are from Allanson (1979).

Cations/anions show similar temporal patterns to EC in that concentrations gradually increase from 2001 to 2014 as lake water level declines, most likely due to the influence of lower inflows and the evaporative concentration. These parameters also showed a strong inverse, linear relationship ($r^2 \sim 0.7$) with water level (Figure 3.5).

Elevated Cl concentrations are characteristic of Lake Sibaya when compared with other typical freshwater systems (Allanson 1979) and are attributed to cyclical salt from the ocean as sea spray and fossil sources of chloride within the tertiary sands of its catchment.

Cation/anion data from this study are presented in Figure 3.6 (raw data is in section 3.9) and the data are within the ranges previously measured in the lake.

3.3.4 pH

Annual median pH levels measured in the Southern Basin (1980 – 2014) ranged between 7 and 8.4 (Figure 3.4). Based on the available historical data, pH levels do not show any significant temporal trend, nor does it show any clear relationship with water level variations in the lake (Figure 3.5).

Data from this study are presented in Figure 1.7 (raw data in section 3.9). pH levels were within the range previously measured in the lake, and appear to have been relatively stable over time.

3.3.5 Turbidity/Transparency

Allanson (1979) recorded a Secchi disc transparency of Lake Sibaya as 3.2 m, representing relatively “clear’ water, although the possibility of re-suspended sediment particles by wind may reduce transparency at times. It has been assumed that wind action is more relevant in shallower areas of the lake.

During this study, turbidity at all the stations sampled was low, ranging between 1-2 NTU (see raw data in section 3.9), despite the windy conditions during sampling that did not appear to re-suspend bottom sediments nor reduce transparency.

3.3.6 Dissolved Oxygen

Historical data on dissolved oxygen (DO) is limited to the Main Basin and was collected on four occasions from 1967 - 1977 (Figure 3.7) and shows a seasonal signal.

Firstly, DO concentrations were lower in summer (4 - 8 mg/l) compared with winter (8 - 9 mg/ℓ), which was expected as DO saturation levels are influenced by temperature; lower DO saturation concentrations occurred during colder winter months and higher DO saturation concentrations occurred during warmer summer months. Secondly, during summer DO concentrations in the deep Main Basin showed vertical stratification below 25 m water depth. Vertical stratification in temperature (Figure 3.7) suggested that at times bottom waters are temporarily trapped and thus not re-aerated but these did not persist, presumably due to effective wind mixing taking place that prevented permanent hypoxia or even anoxia developing.

During this study DO concentrations reflected well oxygenated conditions throughout the lake (i.e. above 8 mg/l). DO depth profiles measured at Stations D1 (Main Basin) resemble winter profiles measured in this area of the lake during July 1967 (Figure 3.7) but were comparably lower in the Southern Basin, possibly due to weaker exchange characteristic of smaller basins. In summary, Lake Sibaya is generally well-oxygenated and displays a seasonal vertical stratification of concentrations related to temperature, where values drop (~4 mg/l) in deeper water.

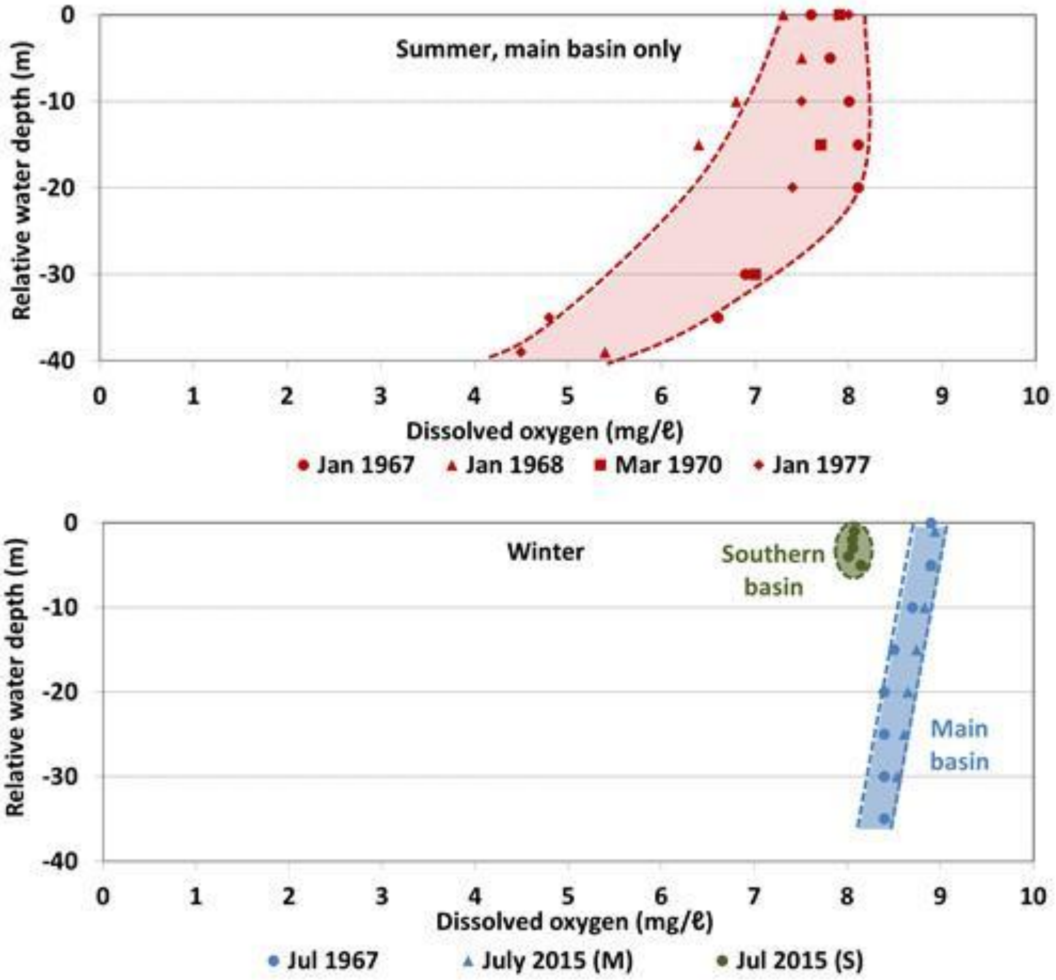


Figure 3.7 **Dissolved oxygen depth profiles measured during summer and winter in the Main Basin (Allanson 1979) and Southern and Main Basins (July 2015)**

3.3.7 Dissolved Inorganic nutrients

Average annual dissolved inorganic phosphate (DIP) and dissolved inorganic nitrogen (NO_x-N plus NH_4-N, DIN) concentrations measured in the Southern Basin (1980 – 2014) are presented in Figure 3.8. Annual average DIP concentrations ranged between 0.01 - 0.12 mg/l, while DIN concentrations ranged from 0.02 - 0.57 mg/l. There were no predictable patterns in the DIN and DIP concentrations, rather the data showed random periods during which concentrations tended to peak (e.g. in 1990 and 2013) although not always simultaneously for DIN and DIP.

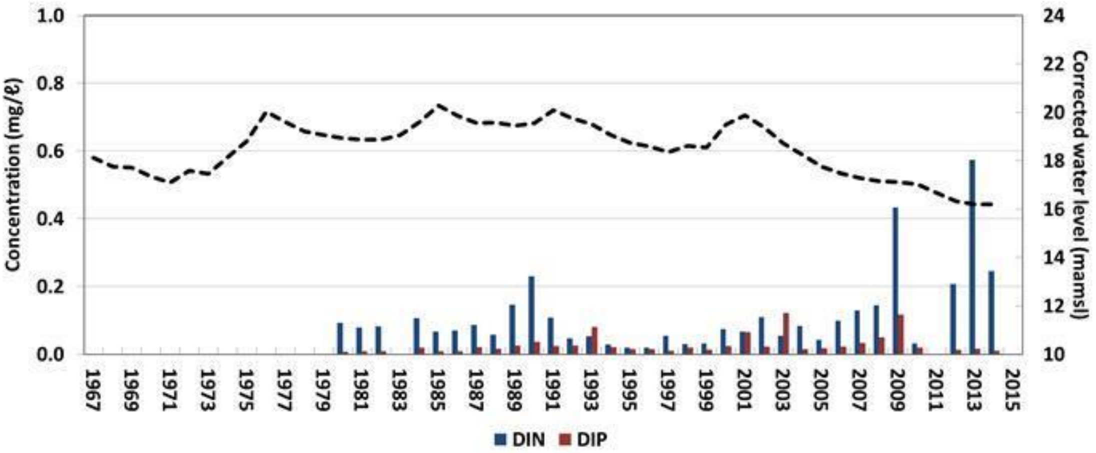


Figure 3.8 Average annual water level, and DIN and DIP concentrations measured in the Southern Basin (W7R1, 1980-2014, DWS)

In the case of DIN, peaks in the Southern Basin tended to coincide with periods with low lake levels, as is illustrated in the weak inverse correlation reflected in Figure 3.9. Thus, it appears that at times when water levels at the sampling station become shallower (e.g. lake levels drop below 18 mamsl) nutrient concentrations tend to increase, perhaps reflecting stronger influence from diffuse runoff from adjacent rural/forestry development.

Humphries and Benitez-Nelson (2013) conducted nutrient studies in June and September 2010, collecting water column samples (Figure 3.10) from the extremities of the lake, where sample values may be strongly influenced by localised effects and thus the data may not be simply extrapolated to the deeper parts of the lake. Signs of nutrient enrichment were found in sediments of the Western Arm (Figure 3.11). Sediment cores from the Western and Northern Arms were sectioned and dated using ^{210}Pb, ^{137}Cs and ^{14}C and nutrient concentrations were then determined for each section (Figure 3.11). An abrupt 2-3 fold increase in sediment nutrient concentrations was evident in the Western Arm in around 1900 that was not evident in the Northern Arm. The authors concluded that the increase in sediment nutrient concentrations in the Western Arm coincided with increased human settlement and the development of Mseleni Town, as well as the development of forestry there. The data from this study did not show these elevated DIN/DIP concentrations in the

Western Arm (Figure 3.12) but since the sample point is not located at the western extremity where influence from the rural development would be most pronounced this is not surprising. DIN concentrations in the Southern Basin, however, were slightly elevated compared with the rest of the lake.

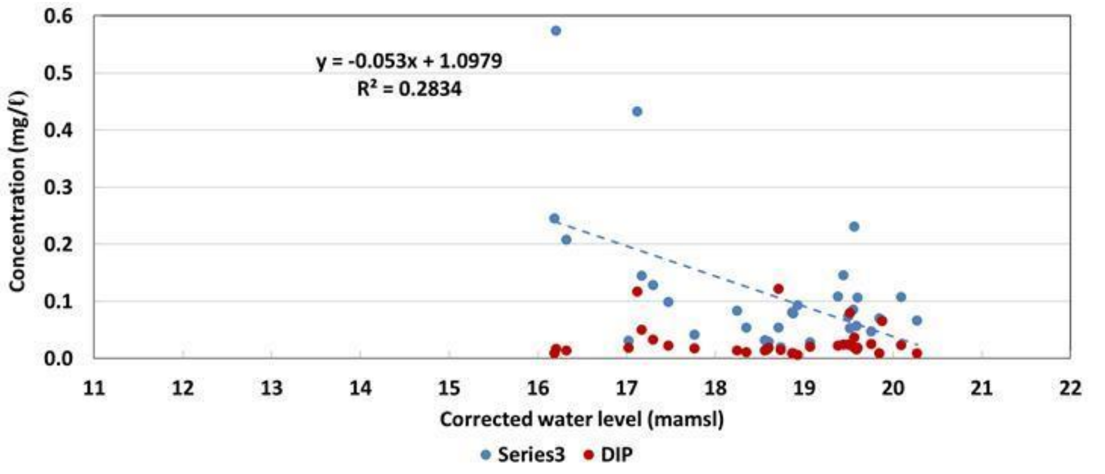


Figure 3.9 Relationship between average annual water level, and DIN and DIP concentrations in the Southern Basin (W7R1, 1980-2014, DWS)

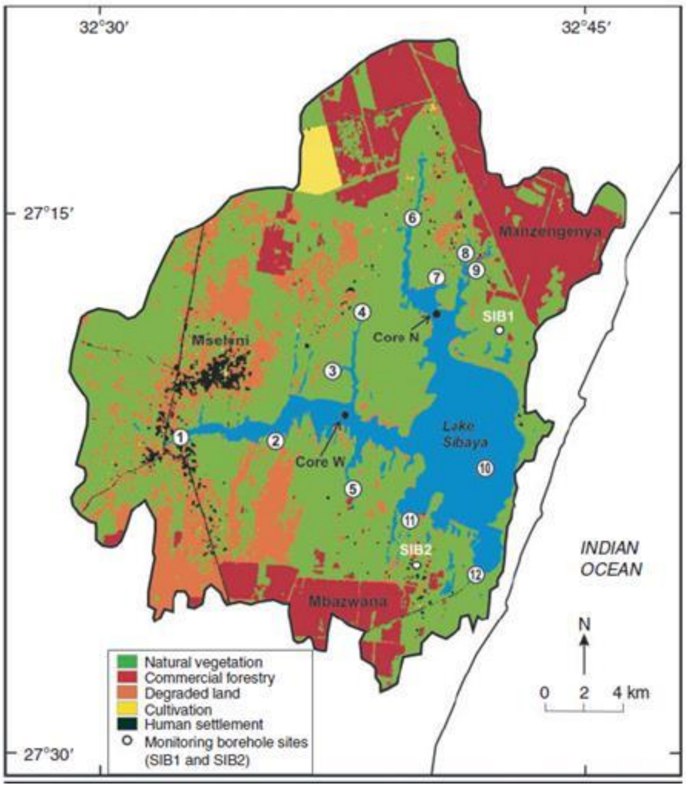


Figure 3.10 Sampling stations in Lake Sibaya during June and September 2010 (Humphries and Benitez-Nelson 2013)

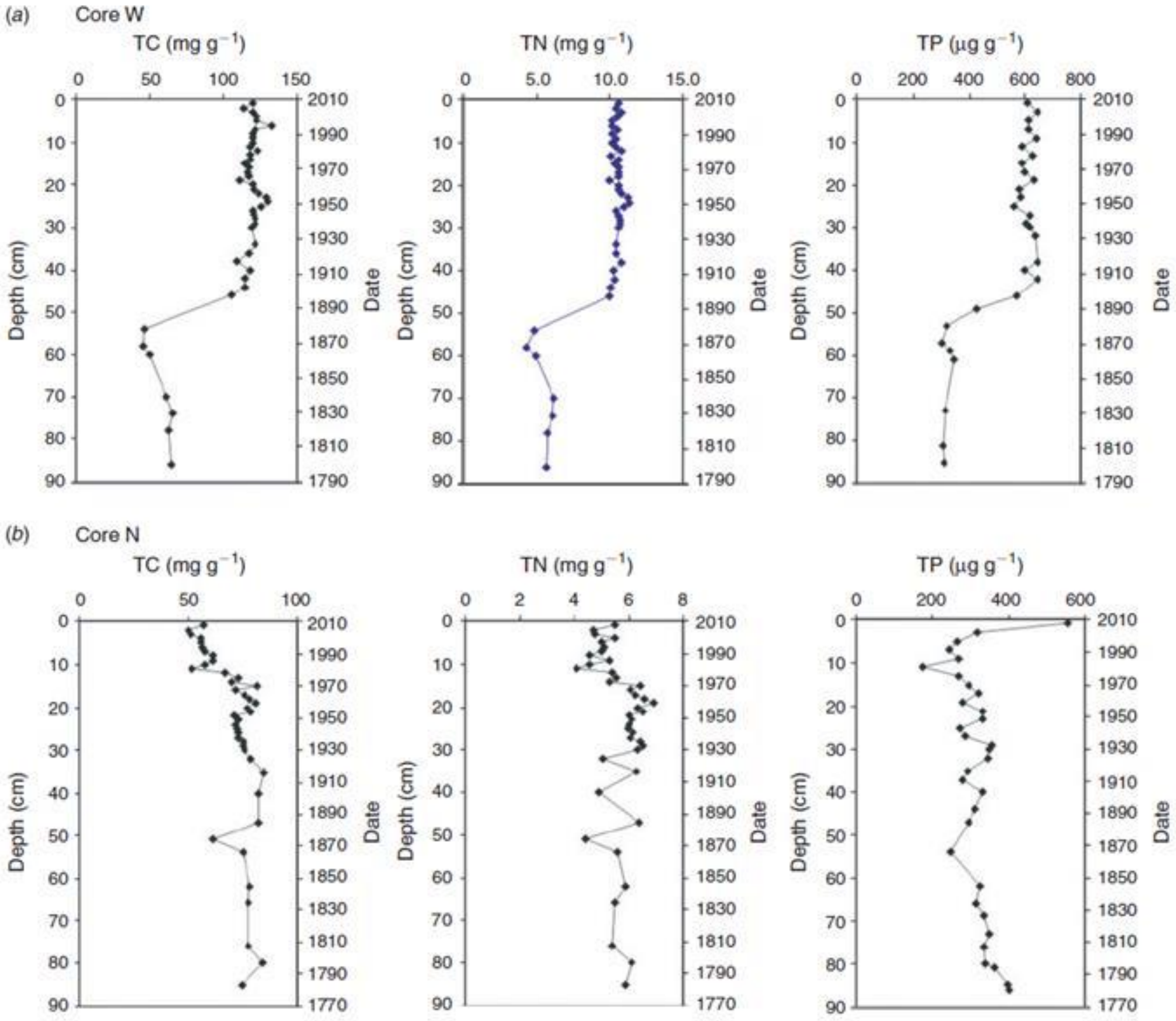


Figure 3.11 Distribution of Total Carbon (TC), Total nitrogen (TN) and Total phosphorous (TP) at different depths per sample event in the western (core W) and northern (Core N) (Humphries and Benitez-Nelson 2013)

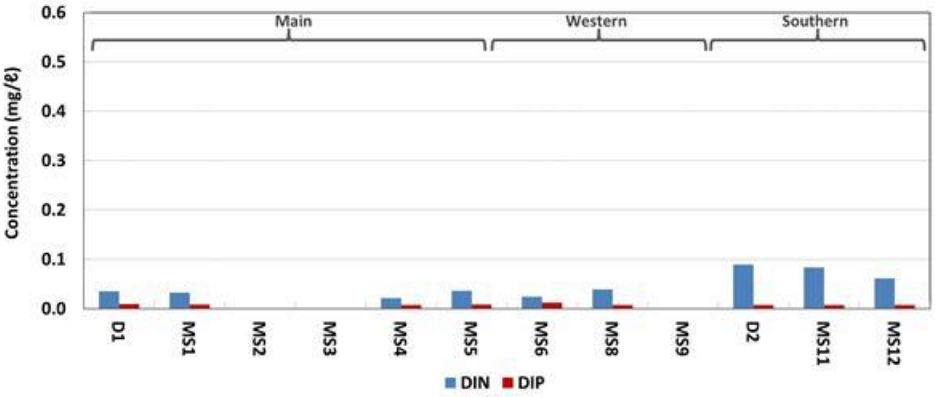


Figure 3.12 DIN and DIP concentrations at various locations in Lake Sibaya, 14-16 July 2015

In summary, the nutrient data suggest that rural/forestry development have influenced conditions in the Western Arm and Southern Basin, especially in the shallower peripheral areas. Although likely sources are difficult to distinguish, the (unnatural) elevation of nutrients in a closed lake system, which acts as a sink, indicates that Lake Sibaya poses a high risk for eutrophication. “Re-setting” or “flushing” of excess nutrients - once introduced - is almost impossible without mechanical intervention.

3.3.8 Toxic substances

Accumulation of toxic substances in Lake Sibaya was partly addressed in a recent study that focussed on DDT (Humphries 2013). DDT was introduced for malaria control in 1946 and, although its use was banned for agricultural purposes in 1976, it remains in use around Lake Sibaya as an indoor spray to control mosquitos (Humphries 2013). During January and March 2012, sediment surface samples were collected from 11 stations covering the muddy (depositional) areas of Lake Sibaya (Figure 3.13). Based on comparison of results with recommended quality guidelines (UNEP/CSIR 2009), most stations (except for stations 2 and 3 draining into the Western Arm) did not comply (Table 3.1) while three, draining into the Western Arm, exceeded probable effects thresholds for aquatic biota.

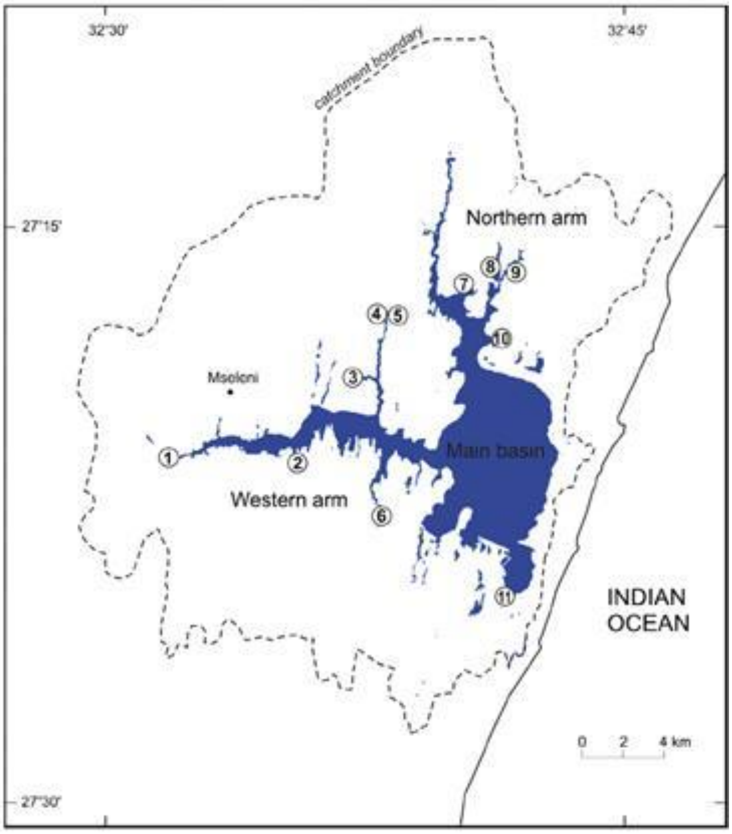


Figure 3.13 Surface sediment sampling station in Lake Sibaya collected for DDT analysis (Humphries 2013)

Table 3.1 DDT levels in sediment from Lake Sibaya compared with recommended quality guidelines (Humphries 2013)

REGION	STATION	DDT (ng/g)	COMPLIANCE TO RECOMMENDED GUIDELINES FOR TOTAL DDT (CSIR/UNEP 2009)	
			Target (3.89 ng/g)	Probable effects threshold (51.7 ng/g)
Western	1	91.5	No	No
	2	1.8	Yes	Yes
	3	0.8	Yes	Yes
	4	71.1	No	No
	5	123	No	No
	6	14.6	No	Yes
Northern	7	15.8	No	No
	8	17.4	No	No
	9	70.6	No	No
	10	41.5	No	No
Southern	11	26.6	No	No

The sampling stations were selected to track worst case conditions (i.e. it targeted muddy, depositional areas) and may not necessarily represent sediment conditions throughout the lake. Nonetheless they pose a warning of DDT accumulation that is expected to intensify if current DDT-based mosquito control practices continue.

3.4 Data summary for application in EcoClassification and response curves

3.4.1 Electrical conductivity

For the purposes of this study it was assumed that the Electrical Conductivity (EC) in the Southern Basin is similar to that in the other EWR zones at times when the Southern Basin is connected to the Main Basin. This assumption was supported by the data collected in this water quality study in July 2015, which showed similar EC values across the lake. Within the baseline period EC and water level data were collected from the Southern Basin from 1980-2014 (Station W7R1), a period when the Southern Basin was nearly permanently connected to the Main Basin. A relationship between EC and lake volume was developed for each EWR zone based on a known relationship between water level (WL) and volume (using bathymetric data). In all instances EC showed a strong inverse linear relationship with volume (Figure 3.14).

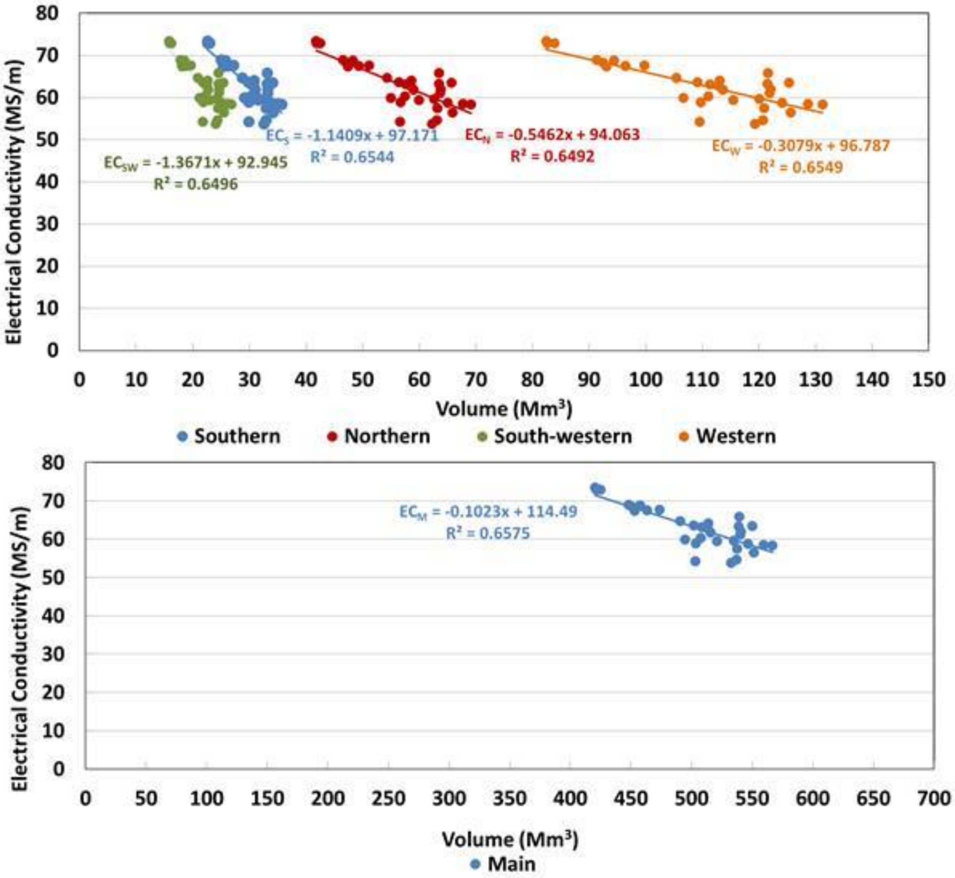


Figure 3.14 Relationship calculated between Electrical Conductivity (EC) and volume in each of the arms and basins in Lake Sibaya

3.4.2 Dissolved nutrients

To estimate DIN and DIP concentrations, the long-term data set in the Southern Basin was used (Table 3.2). For the purposes of this assessment, each EWR zone was subdivided into “shallow” waters (volume <2 m water depth) and “deep” waters (volume >2 m water depth). To separate deep and shallow water concentrations it was assumed that nutrient concentrations sampled at WL>18 masl in the Southern Basin represented deep waters and concentrations from WL <18 masl represented shallow waters. Because the station W7R1 is situated in the Southern Basin, the shallow water DIN/DIP concentrations most likely reflected impacts from forestry and rural development in this area and was thus equated to baseline concentrations for shallow waters in impacted areas (i.e. Southern Basin and Western Arm). For the other shallower (unimpacted areas): the Northern Arm, Southwestern Basin and Main Basin, the deep water values were used.

For DIN and DIP it was assumed that natural concentrations throughout the lake were similar to the baseline deep waters. These concentrations were comparable to generic pristine concentrations assumed for South African freshwater systems by De Villiers and

Thiart (2007). A summary of the DIN and DIP concentrations used for the EWR zones is provided in Table 3.2.

Table 3.2 Summary of DIN and DIP concentrations as applied in the for EcoClassification and response curves

Description	DIN (mg/l	DIP (mg/l)
Average concentration (>18 masl) representative of baseline deep waters (>2 m water depth) in all arms/basins (DWS, Station W7R1 and July 215 data)	0.07	0.02
Average concentration (<18 masl) representative of baseline shallow waters (<2 m water depth) in Western Arm and Southern Basin (DWS, Station W7R1 and July 215 data)	0.23	0.04
Average concentration assumed or baseline shallow waters (<2 m water depth) in Northern Arm, Main Basin and Southwestern Basin	0.07	0.02
Assumed natural (reference) concentrations for entire Lake Sibaya	0.07	0.02

3.4.3 Dissolved oxygen

Lake Sibaya was generally well-oxygenated (DO>7.5 mg/l) during the baseline period and in its natural state, but the deeper parts of the Main Basin are not necessarily so (Allanson 1979). As a result of vertical stratification that prevents mixing of oxygen rich surface with deeper layers, DO in water deeper than 25 m may drop to ~4 mg/l. Average DO concentrations per depth were calculated from the DO profile data collected at a depth of 40 m in the Main Basin. These data were extrapolated to depths shallower than 25 m and a relationship derived for DO at different depths for the Main Basin (Figure 3.15):

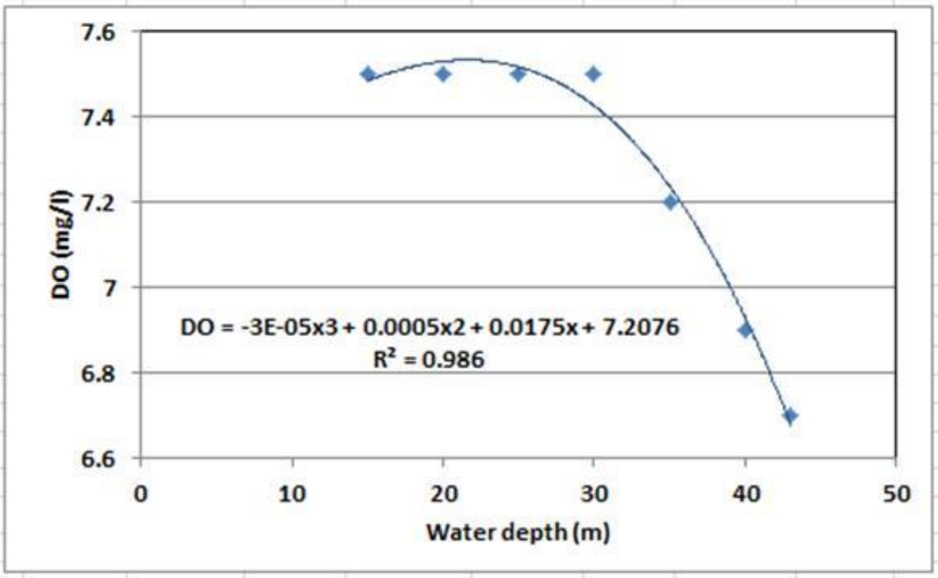


Figure 3.15 Estimated relationship between water depth and depth average DO concentration in the Main Basin of Lake Sibaya

3.4.4 Turbidity

Based on historical anecdotal data (e.g. Allanson 1979), Lake Sibaya is naturally a clear system and based on the data collected in this study the condition has not changed (<5 NTU), despite their having been windy conditions at the time of sampling. Natural and baseline were assumed to be the same but relationships were derived for any flow related indicators and turbidity (i.e. lake is not fed by a turbid catchment). This is based on the assumption that nutrient loading into the lake is not flow related and so will not increase from the baseline in response to changes in water level.

3.4.5 Toxic substances

The study by Humphries (2013) indicated accumulation of DDT in the extremities of the Western Arm, Northern Arm and Southern Basin (no data was collected from Southwestern or Main Basin). Therefore, for the purposes of this study a qualitative expert opinion was provided in relation to toxic substances, where required.

3.5 EcoClassification

For the purposes of this assessment the EcoClassification for water quality follows a modified approach adopted for estuaries (WRC 2012). This EcoClassification approach scores water quality in terms of:

- Salinity (in the case of Lake Sibaya – Electrical Conductivity)
- Inorganic nutrients (DIN/DIP)
- Dissolved oxygen
- Turbidity
- Toxic substances.

Similarity between Baseline (Present State) and Natural (Reference Condition) are calculated using Czekanowski's similarity index: $\underline{\sum(\min(\mathrm{ref,pres})}\ \ (\sum \mathrm{ref} + \sum \mathrm{pres})/2$.

3.5.1 Method description

For EC, monthly water levels (WL) determined for the Baseline (present day) and Natural state (reference) was separated into range categories. For each of the ranges, a characteristic EC was derived from the linear relationship between WL and EC (see Figure 1.6), using the mid-WL to calculate the EC concentration. Using the distribution of WL ranges, and associated EC, the similarity between baseline and natural was calculated (Table 3.3).

Table 3.3 Similarity scores for EC

	NATURAL (REFERENCE)								BASELINE (PRESENT)							
	% state occurrence WL	Electrical conductivity (mS/m)						Average Conc	% state occurrence	Electrical conductivity (mS/m						Average Conc
		56	59	63	67	70	74			56	59	63	67	70	74	
Main		7	34	40	19	0	0	62		7	33	25	24	10	1	63
WL 21-20 amslm	7	7							7	7						
WL 20-19 amslm	34		34						33		33					
WL 19-18 amslm	40			40					25			25				
WL 18-17 amslm	19				19				24				24			
WL 17-16 amslm	0					0			10					10		
WL 16-15 amslm	0						0		1						1	
Southern		7	34	40	19	0	0	62		7	33	25	24	10	1	63
WL 21-20 amslm	7	7							7	7						
WL 20-19 amslm	34		34						33		33					
WL 19-18 amslm	40			40					25			25				
WL 18-17 amslm	19				19				24				24			
WL 17-16 amslm	0					0			10					10		
WL 16-15 amslm	0						0		1						1	
Western		7	34	40	19	0	0	62		7	33	25	24	10	1	63
WL 21-20 amslm	7	7							7	7						
WL 20-19 amslm	34		34						33		33					
WL 19-18 amslm	40			40					25			25				
WL 18-17 amslm	19				19				24				24			
WL 17-16 amslm	0					0			10					10		
WL 16-15 amslm	0						0		1						1	
South-western		7	34	40	19	0	0	62		7	33	25	24	10	1	63
WL 21-20 amslm	7	7							7	7						
WL 20-19 amslm	34		34						33		33					
WL 19-18 amslm	40			40					25			25				
WL 18-17 amslm	19				19				24				24			
WL 17-16 amslm	0					0			10					10		
WL 16-15 amslm	0						0		1						1	
Northern		7	34	40	19	0	0	62		7	33	25	24	10	1	63
WL 21-20 amslm	7	7							7	7						
WL 20-19 amslm	34		34						33		33					
WL 19-18 amslm	40			40					25			25				
WL 18-17 amslm	19				19				24				24			
WL 17-16 amslm	0					0			10					10		
WL 16-15 amslm	0						0		1						1	
Main basin																99.2
Southern basin																99.2
Western arm																99.2
South-western basin																99.2
Northern arm																99.2

For DIN and DIP the concentrations applied for the natural (Reference) and Baseline (present day) in the EcoClassification are presented in Table 3.2. In addition, the volume fraction of deep waters (volume where water depths >2 m) versus shallow waters (volume where water depths <2 m) were calculated from available data for each EWR zone to calculate a weighted contribution from these two depth classes in each arm/basin (Table 3.4).

Table 3.4 Weighted contributions of DIN and DIP for each arm/basin

BASIN/ARM	TOTAL (Mm3)	SHALLOW	%Vol Weight	DEEP	%Vol Weight
Main	511.5	3.591	0.7	507.909	99.3
South	30.622	0.386	1.3	30.236	98.7
Western	112.43	1.422	1.3	111.008	98.7
South-western	22.445	0.398	1.8	22.047	98.2
Northern	58.216	1.102	1.9	57.114	98.1

Using the above information the similarity between baseline (present) and natural (reference) was calculated (Table 3.5 and Table 3.6).

Table 3.5 Similarity scores for DIN

	Natural (Reference)				**Baseline (Present)**			
Zone & Depth class	**% vol**	**DIN (mg/l)**		**Average**	**% vol**	**DIN (mg/l)**		**Average**
	of basin	**0.07**	**0.23**	**conc**	**of basin**	**0.07**	**0.23**	**conc**
Main Basin		100.0	0.0	0.070		100.0	0.0	0.070
Deep	99.3	99.3			99.3	99.3		
Shallow	0.7	0.7			0.7	0.7		
Southern arm		100.0	0.0	0.070		98.7	1.3	0.072
Deep	98.7	98.7			98.7	98.7		
Shallow	1.3	1.3			1.3		1.3	
Western arm		100.0	0.0	0.070		98.7	1.3	0.072
Deep	98.7	98.7			98.7	98.7		
Shallow	1.3	1.3			1.3		1.3	
Southwestern arm		100.0	0.0	0.070		100.0	0.0	0.070
Deep	98.2	98.2			98.2	98.2		
Shallow	1.8	1.8			1.8	1.8		
Northern arm		100.0	0.0	0.070		100.0	0.0	0.070
Deep	98.1	98.1			98.1	98.1		
Main basin								100.0
Southern basin								98.6
Western arm								98.6
Southwestern basin								100.0
Northern arm								100.0

Table 3.6 Similarity scores for DIP

	Natural (reference)				**Baseline (Present)**			
Zone & Depth class	**% vol of basin**	**DIP (mg/l) 0.02**	**0.04**	**Average conc**	**% vol of basin**	**DIP (mg/l) 0.02**	**0.04**	**Average conc**
Main Basin		100.0	0.0	0.020		100.0	0.0	0.020
Deep	99.3	99.3			99.3	99.3		
Shallow	0.7	0.7			0.7	0.7		
Southern arm		100.0	0.0	0.020		98.7	1.3	0.020
Deep	98.7	98.7			98.7	98.7		
Shallow	1.3	1.3			1.3		1.3	
Western arm		100.0	0.0	0.020		98.7	1.3	0.020
Deep	98.7	98.7			98.7	98.7		
Shallow	1.3	1.3			1.3		1.3	
Southwestern arm		100.0	0.0	0.020		100.0	0.0	0.020
Deep	98.2	98.2			98.2	98.2		
Shallow	1.8	1.8			1.8	1.8		
Northern arm		100.0	0.0	0.020		100.0	0.0	0.020
Deep	98.1	98.1			98.1	98.1		
Main basin								100.0
Southern basin								99.4
Western arm								99.4
Southwestern basin								100.0
Northern arm								100.0

For dissolved oxygen well-oxygenated concentrations (>7.5 mg/l) were assumed for all EWR zones in the lake, except the deep Main Basin where vertical stratification at times results in a reduction in DO with depth (Figure 1.15).

Using the distribution of WL ranges and its relationship with depth-averaged DO for the Main Basin and well-oxygenated DO (7.5 mg/l) for the rest of the lake, the similarity between the baseline (present) and natural (reference) was calculated (Table 3.7).

Table 3.7 Similarity scores for DO

	Natural (Reference)									Baseline (Present)								
	% state	Dissolved oxyxgen (mg/l)							Average	% state	Dissolved oxyxgen (mg/l)							Average
	occurrence	6.4	6.5	6.6	6.7	6.8	6.9	7.5	Conc	occurrence	6.4	6.5	6.6	6.7	6.8	6.9	7.5	Conc
Main	WL	7	34	40	19	0	0	0	6.6	WL	7	33	25	24	10	1	0	6.6
WL 21-20 amslm	7	7								7	7							
WL 20-19 amslm	34		34							33		33						
WL 19-18 amslm	40			40						25			25					
WL 18-17 amslm	19				19					24				24				
WL 17-16 amslm	0					0				10					10			
WL 16-15 amslm	0						0			1						1		
Southern		0	0	0	0	0	0	###	7.5		0	0	0	0	0	0	100	7.5
WL 21-20 amslm	7							7		7							7	
WL 20-19 amslm	34							34		33							33	
WL 19-18 amslm	40							40		25							25	
WL 18-17 amslm	19							19		24							24	
WL 17-16 amslm	0							0		10							10	
WL 16-15 amslm	0							0		1							1	
Western		0	0	0	0	0	0	###	7.5		0	0	0	0	0	0	100	7.5
WL 21-20 amslm	7							7		7							7	
WL 20-19 amslm	34							34		33							33	
WL 19-18 amslm	40							40		25							25	
WL 18-17 amslm	19							19		24							24	
WL 17-16 amslm	0							0		10							10	
WL 16-15 amslm	0							0		1							1	
South-western		0	0	0	0	0	0	###	7.5		0	0	0	0	0	0	100	7.5
WL 21-20 amslm	7							7		7							7	
WL 20-19 amslm	34							34		33							33	
WL 19-18 amslm	40							40		25							25	
WL 18-17 amslm	19							19		24							24	
WL 17-16 amslm	0							0		10							10	
WL 16-15 amslm	0							0		1							1	
Northern		0	0	0	0	0	0	###	7.5		0	0	0	0	0	0	100	7.5
WL 21-20 amslm	7							7		7							7	
WL 20-19 amslm	34							34		33							33	
WL 19-18 amslm	40							40		25							25	
WL 18-17 amslm	19							19		24							24	
WL 17-16 amslm	0							0		10							10	
WL 16-15 amslm	0							0		1							1	
Main basin																		99.8
Southern basin																		100.0
Western arm																		100.0
South-western basin																		100.0
Northern arm																		100.0

Average turbidity in Lake Sibaya was assumed to be <5 NTU in both shallow and deeper water throughout the system for natural and baseline conditions. Based on this assumption, the similarity score for all EWR sites was 100 (Table 3.8).

EcoClassification for toxic substances was based on expert judgement considering the limited data on DDT accumulation in the muddy extremities of the Southern Basin, Northern Arm and Western Arm. No toxicity data were available for the Southwestern Basin, but for the purposes of this study it was assumed that the lake extremities may also have been affected. The Main Basin was assumed to be the least affected. Assuming that contamination would largely be limited to sediments in the extremities of the arms and smaller Basins, the following similarity scores were allocated (Table 3.9).

Table 3.8 Similarity scores for turbidity

	NATURAL (REFERENCE)				BASELINE (PRESENT)			
	% vol of	NTU		Average Conc	% vol of	NTU		Average Conc
		5	10			5	10	
Main		100.0	0.0	5		100.0	0.0	5
Deep	99.3	99.3			99.3	99.3		
Shallow	0.7	0.7			0.7	0.7		
Southern		100.0	0.0	5		100.0	0.0	5
WL 21-20 amslm	98.7	98.7			98.7	98.7		
WL 20-19 amslm	1.3	1.3			1.3	1.3		
Western		100.0	0.0	5		100.0	0.0	5
WL 21-20 amslm	98.7	98.7			98.7	98.7		
WL 20-19 amslm	1.3	1.3			1.3	1.3		
South-western		100.0	0.0	5		100.0	0.0	5
WL 21-20 amslm	98.2	98.2			98.2	98.2		
WL 20-19 amslm	1.8	1.8			1.8	1.8		
Northern		100.0	0.0	5		100.0	0.0	5
WL 21-20 amslm	98.1	98.1			98.1	98.1		
WL 20-19 amslm	1.9	1.9			1.9	1.9		
Main basin								100.0
Southern basin								100.0
Western arm								100.0
South-western basin								100.0
Northern arm								100.0

Table 3.9 Similarity scores for toxicity

EWR Zone	Toxic substance similarity score
Main	90
Southern	80
Western	80
South-western	80
Northern	80

3.5.2 Results

The individual similarity scores for the selected water quality parameters were combined to obtain the water quality scores for Present Ecological State (PES). Using a modified version of the estuaries method (DWAF 2004) the parameter scores were weighted with EC at 40% and OTHER WQ, comprising an average of the DIN/DIN, DO, turbidity and toxicity scores, weighted at 60%.

The scores for water quality for each area of the basin are provided below (Table 3.10).

Table 3.10 Results of water quality EcoClassification

Main Basin	**Score**	**Weight**	**Weighted score**
Conductivity	99.2	0.4	39.7
Other WQ (average of 1-4)	94.9	0.6	57.0
1. DIN/DIP	100.0		
2. DO	99.8		
3. Turbidity	90.0		
4. Toxic substances	90.0		
WQ Score			97
Southern Basin			
Conductivity	99.2	0.4	39.7
Other WQ (average of 1-4)	89.7	0.6	53.8
1. DIN/DIP	99.0		
2. DO	100.0		
3. Turbidity	80.0		
4. Toxic substances	80.0		
WQ Score			94
Western Arm			
Conductivity	99.2	0.4	39.7
Other WQ (average of 1-4)	89.7	0.6	53.8
1. DIN/DIP	99.0		
2. DO	100.0		
3. Turbidity	80.0		
4. Toxic substances	80.0		
WQ Score			94
Southwestern Basin			
Conductivity	99.2	0.4	39.7
Other WQ (average of 1-4)	90.0	0.6	54.0
1. DIN/DIP	100.0		
2. DO	100.0		
3. Turbidity	80.0		
4. Toxic substances	80.0		
WQ Score			94
Northern Arm			
Conductivity	99.2	0.4	39.7
Other WQ (average of 1-4)	90.0	0.6	54.0
1. DIN/DIP	100.0		
2. DO	100.0		
3. Turbidity	80.0		
4. Toxic substances	80.0		
WQ Score			94

3.6 Identification of indicators

3.6.1 Indicator list for water quality

The list of water quality indicators selected, the reasons for their selection (Table 3.11), and their expected responses to water level (Table 3.12), where relevant, are provided below.

Table 3.11 Water quality indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Electrical conductivity	Change may affect biological components
Dissolved oxygen (Main Basin only)[16]	Change may affect biological components
Turbidity[17]	Not selected
Volume where DIN ~0.07 mg/l	Change may affect biological components
Volume where DIN ~0.23 mg/l	
Volume where DIP ~0.02 mg/l	
Volume where DIP ~0.04 mg/l	

Table 3.12 Water quality indicators and predicted response to water level changes

Indicator	Definition	Predicted change	Reference
Electrical Conductivity	mS/m	EC to increase with decrease in WL (expressed as Volume)	DWS data (W7R1)
Dissolved Oxygen (Main Basin only)	mg/l	Depth average DO to increase with decrease in WL (expressed as Depth)	Allanson (1979)
Volume where DIN ~0.07 mg/l	mg/l	No predicted change with WL as cause of nutrient changes are non-flow related (rural forestry diffuse runoff into shallower peripheries). However, to provide an indication of volume of water at specific DIN/DIP concentrations (distinguishing between shallow and deeper waters) these indicators were included	DWS data (W7R1)
Volume where DIN ~0.23 mg/l			
Volume where DIP ~0.02 mg/l			
Volume where DIP ~0.04 mg/l			

3.6.2 Linked indicators

The water quality indicators were linked to the following hydrological indicators Table 3.13.

---

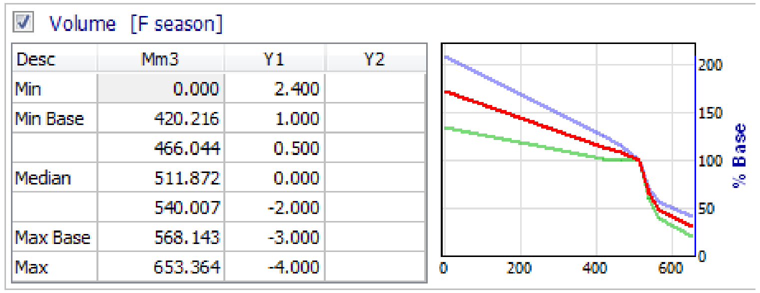
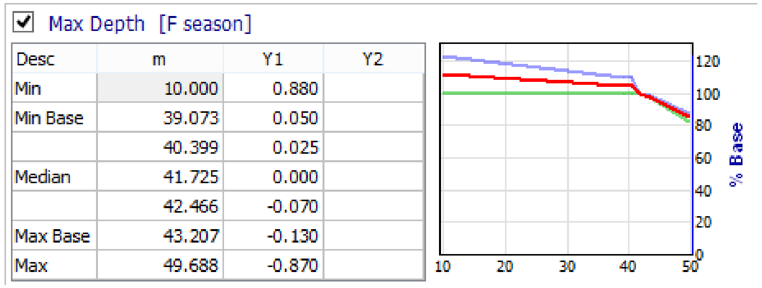
[16] DO was only included as an indicator in the main basin where changes in water depth may result in changes in depth averaged DO concentrations. All other Basins/Arm are shallow and well-oxygenated and are not expected to change with changes in WL. This is based on the assumption that the non-flow related nutrient input remain as that of the baseline (i.e. no increase in phytoplankton growth above baseline that could influence DO levels)

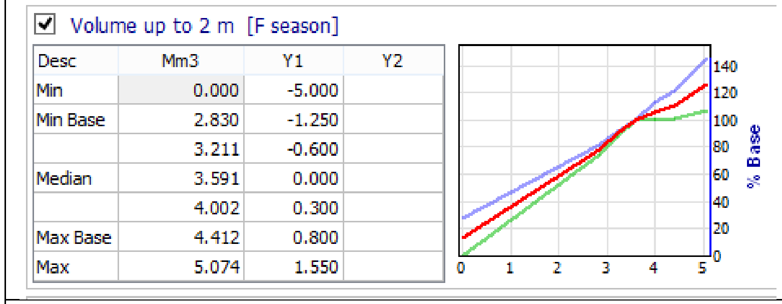
[17] Turbidity was not selected as a WQ indicator as the system remains very clear and there are no expected flow related changes. This is based on the assumption that the non-flow related nutrient input remain as that of baseline (i.e. (i.e. no increase in phytoplankton growth above baseline that could influence turbidity)

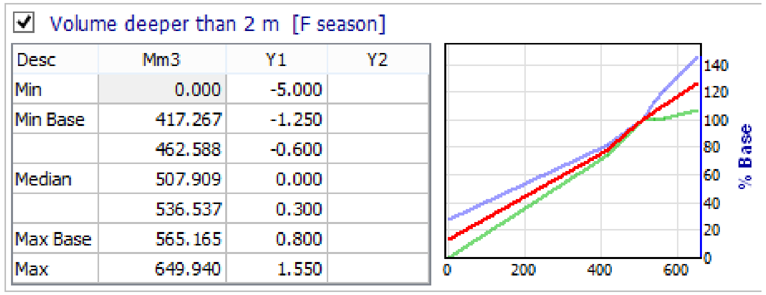
Table 3.13 Linked indicators and motivation for water quality

Indicator	Linked indicator	Motivation
Electrical Conductivity	Volume	Good linear relationship between EC and Volume that can be extrapolated to future changes in WL
Dissolved Oxygen (Main Basin only)	Depth	Good polynomial relationship between depth average DO and Depth which can be extrapolated to future changes in WL
Volume where DIN ~ 0.07 mg/l	Volume up to 2m Volume deeper than 2 m	To provide an indication of volume of water at specific DIN/DIP concentrations (distinguishing between shallow and deeper waters)
Volume where DIN ~ 0.23 mg/l	Volume up to 2m	
Volume where DIP ~ 0.02 mg/l	Volume up to 2m Volume deeper than 2 m	
Volume where DIP ~ 0.04 mg/l	Volume up to 2m	

3.7 Motivations for response curves

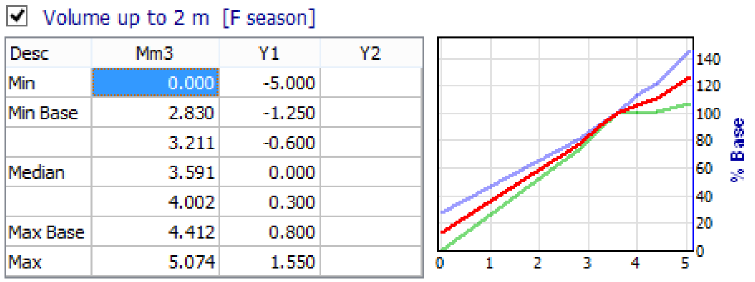
<table>
<tr><td colspan="2">Electrical conductivity (All EWR Zones)</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Volume [F season]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>2.400</td><td></td></tr>
<tr><td>Min Base</td><td>420.216</td><td>1.000</td><td></td></tr>
<tr><td></td><td>466.044</td><td>0.500</td><td></td></tr>
<tr><td>Median</td><td>511.872</td><td>0.000</td><td></td></tr>
<tr><td></td><td>540.007</td><td>-2.000</td><td></td></tr>
<tr><td>Max Base</td><td>568.143</td><td>-3.000</td><td></td></tr>
<tr><td>Max</td><td>653.364</td><td>-4.000</td><td></td></tr>
</table>
</td><td>DWS EC data (W7R1) collected from the Southern Basin (1980-2014) was used. Sampling conducted in July 2015 across other basins showed similar EC levels and it was therefore assumed that the Southern Basin long-term data could be extrapolated to the other basins. Average annual EC were linearly correlated (all r2>0.7) with corresponding average annual volumes in each of the basins, the latter calculated from WL and bathymetry. This relationship was then used to calculate EC responses for all basins./arms (see example response curve). As Volume decreases EC will increase near-linearly (see linear equations for EC versus Volume in various basins/arms in Figure 1.15)</td><td>Medium to Low (2)</td></tr>
<tr><td colspan="2">Dissolved oxygen (Main Basin only)</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Max Depth [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>10.000</td><td>0.880</td><td></td></tr>
<tr><td>Min Base</td><td>39.073</td><td>0.050</td><td></td></tr>
<tr><td></td><td>40.399</td><td>0.025</td><td></td></tr>
<tr><td>Median</td><td>41.725</td><td>0.000</td><td></td></tr>
<tr><td></td><td>42.466</td><td>-0.070</td><td></td></tr>
<tr><td>Max Base</td><td>43.207</td><td>-0.130</td><td></td></tr>
<tr><td>Max</td><td>49.688</td><td>-0.870</td><td></td></tr>
</table>
</td><td>DO information on Lake Sibaya shows a generally well oxygenated systems (DO>7 mg/l) (Allanson 1979, this study). However, during summer DO profiles in the deep Main Basin show some stratification (this is linked to temperature stratification preventing deeper waters from being completely re-oxygenated). This drop in DO typically happen in waters deeper than 25 m from surface. Using the available summer data, depth averaged DO were calculated for 40 m water depth. This data was then used to extrapolate depth averaged DO for shallower lake depths assuming that DO will only drop in water deeper than 25 m from surface, i.e. water depth <25 m do not show marked vertical stratification. The relationship between water depth vs depth averaged DO were then used to derive the response curve. Equation: DO = -0.00003x3 + 0.0005x2 + 0.0175x + 7.2076, where x = water depth</td><td>Medium to Low (2)</td></tr>
</table>

<table>
<tr><td colspan="2">Volume where DIN ~ 0.07 mg/l and Volume where DIN ~0.23 mg/l (All EWR Zones)</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Volume up to 2 m [F season]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>2.830</td><td>-1.250</td><td></td></tr>
<tr><td></td><td>3.211</td><td>-0.600</td><td></td></tr>
<tr><td>Median</td><td>3.591</td><td>0.000</td><td></td></tr>
<tr><td></td><td>4.002</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>4.412</td><td>0.800</td><td></td></tr>
<tr><td>Max</td><td>5.074</td><td>1.550</td><td></td></tr>
</table>


☑ Volume deeper than 2 m [F season]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>417.267</td><td>-1.250</td><td></td></tr>
<tr><td></td><td>462.588</td><td>-0.600</td><td></td></tr>
<tr><td>Median</td><td>507.909</td><td>0.000</td><td></td></tr>
<tr><td></td><td>536.537</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>565.165</td><td>0.800</td><td></td></tr>
<tr><td>Max</td><td>649.940</td><td>1.550</td><td></td></tr>
</table>

</td><td>DIN estimated from long-term data set from station W7R1 (DWS) For this assessment, each basin/arm was subdivided into shallow waters (<2 m water depth) and “deeper waters” (> 2 m water depth). To separate “deeper” and “shallow” water concentrations it was assumed that DIN concs sampled at WL>18 masl represented “deeper waters” and concs from WL <18 masl represented “shallower waters”. Because the W7R1 is situated in the Southern Basin, the “shallow waters” DIN concentrations most likely reflected impacts from rural/forestry development and forestry in this area. Thus it could be equated to the baseline concentration for the Southern Basin and Western Arm (both impacted by increased rural development and forestry), but no really for “shallow waters” in the other basins/arms that were largely unimpacted. Therefore the concentrations of the “deeper waters” were also assumed for the “shallow waters” in the unimpacted arms/basins, namely Northern Arm, Southwestern Basin and Main Basin.

DIN non-flow related (rural forestry diffuse runoff into shallower peripheries). However, to provide an indication of volume of water at specific DIN concentrations (distinguishing between shallow and deeper waters) these indicators were included. Response curves are provided for shallow waters (i.e. volume up to 2 m) and deeper waters (i.e. volume deeper than 2 m) assuming a positive linear relationship, i.e. as volume increase water with DIN as selected concentration increases.</td><td>Medium to low (2)</td></tr>
</table>

<table>
<tr><td colspan="2">Volume where DIP ~ 0.02 mg/l and Volume where DIP ~0.04 mg/l (All EWR Zones)</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Volume up to 2 m [F season]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
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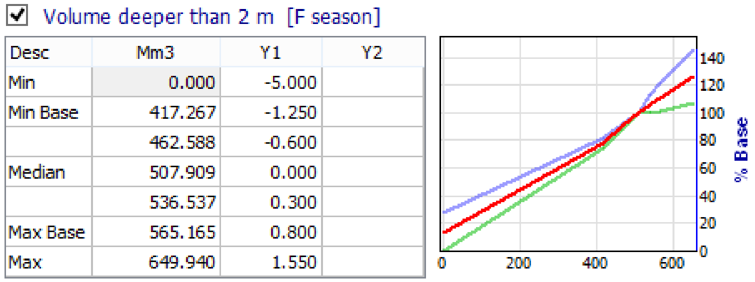
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<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
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</table>

</td><td>DIP estimated from long-term data set from station W7R1 (DWS). For this assessment, each basin/arm was subdivided into shallow waters (<2 m water depth) and “deeper waters” (> 2 m water depth). To separate “deeper” and “shallow” water concentrations it was assumed that DIP concentrations sampled at WL>18 masl represented “deeper waters” and concs from WL <18 masl represented “shallower waters”. Because the W7R1 is situated in the Southern Basin, the “shallow waters” DIP concentrations most likely reflected impacts from rural/forestry development and forestry in this area. Thus it could be equated to the baseline concentration for the Southern Basin and Western Arm (both impacted by increased rural development and forestry), but no really for “shallow waters” in the other basins/arms that were largely unimpacted. Therefore the concentrations of the “deeper waters” were also assumed for the “shallow waters” in the unimpacted arms/basins, namely Northern Arm, Southwestern Basin and Main Basin.

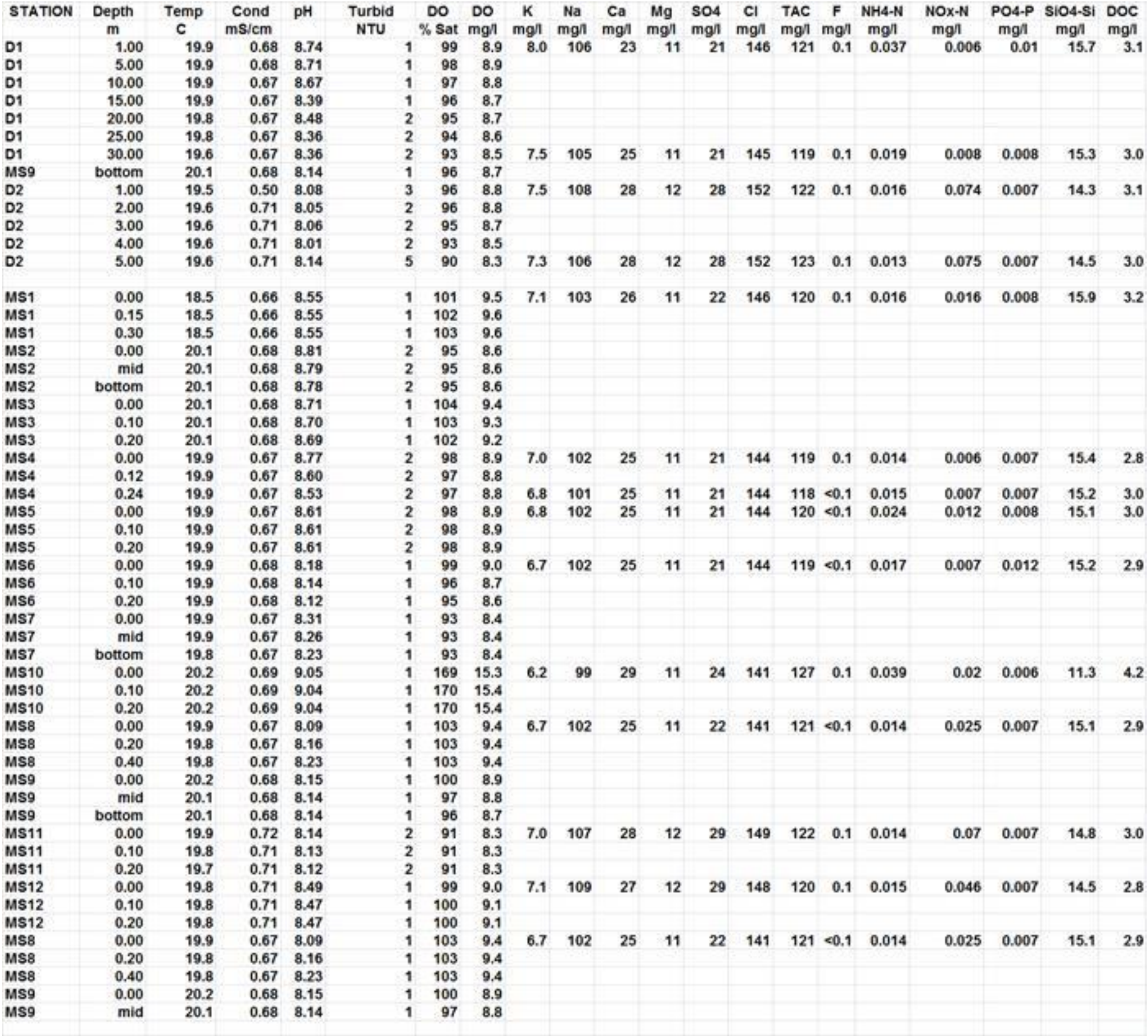
DIP non-flow related (rural forestry diffuse runoff into shallower peripheries). However, to provide an indication of volume of water at specific DIP concentrations (distinguishing between shallow and deeper waters) these indicators were included. Response curves are provided for shallow waters (i.e. volume up to 2 m) and deeper waters (i.e. volume deeper than 2 m) assuming a positive linear relationship, i.e. as volume increase water with DIP as selected concentration increases.</td><td>Medium to low (2)</td></tr>
</table>

3.8 Assumptions and limitations

For the water quality study, the following assumptions and limitations apply:

- There were no measured long-term water quality data available for the Western Arm, Southwestern Basin or Northern Arm (much less than for Main Basin and Southern Basin).
- It was assumed that EC concentrations in the Southern lake area are similar to the rest of the lake when the Southern Basin is connected to the Main Basin.
- It was assumed that long-term data on DIN/DIP concentrations in the Southern Basin can be extrapolated to other basins/arms as was done for this study.
- There were no data on toxic substances available other than the DDT study of Humphries (2013), i.e. no indication of herbicides, pesticides and other chemical inputs from forestry, agriculture andrural development.
- It was assumed that nutrient input from non-flow related activities around the lake will not increase from the baseline condition.

3.9 Raw data collected 14-16 July 2015 (this study)



STATION	Depth m	Temp C	Cond mS/cm	pH	Turbid NTU	DO % Sat	DO mg/l	K mg/l	Na mg/l	Ca mg/l	Mg mg/l	SO4 mg/l	Cl mg/l	TAC mg/l	F mg/l	NH4-N mg/l	NOx-N mg/l	PO4-P mg/l	SiO4-Si mg/l	DOC mg/l
D1	1.00	19.9	0.68	8.74	1	99	8.9	8.0	106	23	11	21	146	121	0.1	0.037	0.006	0.01	15.7	3.1
D1	5.00	19.9	0.68	8.71	1	98	8.9													
D1	10.00	19.9	0.67	8.67	1	97	8.8													
D1	15.00	19.9	0.67	8.39	1	96	8.7													
D1	20.00	19.8	0.67	8.48	2	95	8.7													
D1	25.00	19.8	0.67	8.36	2	94	8.6													
D1	30.00	19.6	0.67	8.36	2	93	8.5	7.5	105	25	11	21	145	119	0.1	0.019	0.008	0.008	15.3	3.0
MS9	bottom	20.1	0.68	8.14	1	96	8.7													
D2	1.00	19.5	0.50	8.08	3	96	8.8	7.5	108	28	12	28	152	122	0.1	0.016	0.074	0.007	14.3	3.1
D2	2.00	19.6	0.71	8.05	2	96	8.8													
D2	3.00	19.6	0.71	8.06	2	95	8.7													
D2	4.00	19.6	0.71	8.01	2	93	8.5													
D2	5.00	19.6	0.71	8.14	5	90	8.3	7.3	106	28	12	28	152	123	0.1	0.013	0.075	0.007	14.5	3.0
MS1	0.00	18.5	0.66	8.55	1	101	9.5	7.1	103	26	11	22	146	120	0.1	0.016	0.016	0.008	15.9	3.2
MS1	0.15	18.5	0.66	8.55	1	102	9.6													
MS1	0.30	18.5	0.66	8.55	1	103	9.6													
MS2	0.00	20.1	0.68	8.81	2	95	8.6													
MS2	mid	20.1	0.68	8.79	2	95	8.6													
MS2	bottom	20.1	0.68	8.78	2	95	8.6													
MS3	0.00	20.1	0.68	8.71	1	104	9.4													
MS3	0.10	20.1	0.68	8.70	1	103	9.3													
MS3	0.20	20.1	0.68	8.69	1	102	9.2													
MS4	0.00	19.9	0.67	8.77	2	98	8.9	7.0	102	25	11	21	144	119	0.1	0.014	0.006	0.007	15.4	2.8
MS4	0.12	19.9	0.67	8.60	2	97	8.8													
MS4	0.24	19.9	0.67	8.53	2	97	8.8	6.8	101	25	11	21	144	118	<0.1	0.015	0.007	0.007	15.2	3.0
MS5	0.00	19.9	0.67	8.61	2	98	8.9	6.8	102	25	11	21	144	120	<0.1	0.024	0.012	0.008	15.1	3.0
MS5	0.10	19.9	0.67	8.61	2	98	8.9													
MS5	0.20	19.9	0.67	8.61	2	98	8.9													
MS6	0.00	19.9	0.68	8.18	1	99	9.0	6.7	102	25	11	21	144	119	<0.1	0.017	0.007	0.012	15.2	2.9
MS6	0.10	19.9	0.68	8.14	1	96	8.7													
MS6	0.20	19.9	0.68	8.12	1	95	8.6													
MS7	0.00	19.9	0.67	8.31	1	93	8.4													
MS7	mid	19.9	0.67	8.26	1	93	8.4													
MS7	bottom	19.8	0.67	8.23	1	93	8.4													
MS10	0.00	20.2	0.69	9.05	1	169	15.3	6.2	99	29	11	24	141	127	0.1	0.039	0.02	0.006	11.3	4.2
MS10	0.10	20.2	0.69	9.04	1	170	15.4													
MS10	0.20	20.2	0.69	9.04	1	170	15.4													
MS8	0.00	19.9	0.67	8.09	1	103	9.4	6.7	102	25	11	22	141	121	<0.1	0.014	0.025	0.007	15.1	2.9
MS8	0.20	19.8	0.67	8.16	1	103	9.4													
MS8	0.40	19.8	0.67	8.23	1	103	9.4													
MS9	0.00	20.2	0.68	8.15	1	100	8.9													
MS9	mid	20.1	0.68	8.14	1	97	8.8													
MS9	bottom	20.1	0.68	8.14	1	96	8.7													
MS11	0.00	19.9	0.72	8.14	2	91	8.3	7.0	107	28	12	29	149	122	0.1	0.014	0.07	0.007	14.8	3.0
MS11	0.10	19.8	0.71	8.13	2	91	8.3													
MS11	0.20	19.7	0.71	8.12	2	91	8.3													
MS12	0.00	19.8	0.71	8.49	1	99	9.0	7.1	109	27	12	29	148	120	0.1	0.015	0.046	0.007	14.5	2.8
MS12	0.10	19.8	0.71	8.47	1	100	9.1													
MS12	0.20	19.8	0.71	8.47	1	100	9.1													
MS8	0.00	19.9	0.67	8.09	1	103	9.4	6.7	102	25	11	22	141	121	<0.1	0.014	0.025	0.007	15.1	2.9
MS8	0.20	19.8	0.67	8.16	1	103	9.4													
MS8	0.40	19.8	0.67	8.23	1	103	9.4													
MS9	0.00	20.2	0.68	8.15	1	100	8.9													
MS9	mid	20.1	0.68	8.14	1	97	8.8													

3.10 References

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4 VEGETATION

4.1 Introduction

This Section comprises the summary report for vegetation, and provides:

- Overview of the study area, with focus on delineation of homogenous areas;
- For the EWR sites:
    - EcoClassification assessments for vegetation, with supporting evidence;
    - the DRIFT indicators chosen, and reasons;
    - the relationships between the chosen indicators and water level or other factors, with referenced, supporting motivation.
- Data and the details of any analyses performed.
- EcoSpecs and monitoring actions required to describe and monitor the recommended Ecological Status with respect to vegetation.

4.2 Description of the study area, with respect to vegetation

At a broad scale, Lake Sibaya is surrounded by six vegetation units (Figure 4.1). In general the lake occurs within the Maputaland Coastal Belt vegetation type, but with several distinct and different vegetation units embedded within the geographical extent of Maputaland Coastal Belt, and associated with the lake to various extents. These include Subtropical Freshwater Wetlands, Maputaland Wooded Grassland, Northern Coastal Forest, Subtropical Dune Thicket and Swamp Forest (Mucina & Rutherford 2006).

Maputaland Coastal Belt vegetation is characterised by generally open vegetation with *Syzygium cordatum* scattered or in clumps, with pockets of distinctly different vegetation types, such as Forest types (Sand, Swamp, Dune or Coastal Forest) or Maputaland Wooded Grassland, as well as various wetland types (Mucina & Rutherford 2006). The association of *S. cordatum* with wetter areas (and riparian zones in general) highlights its likely phreatophytic nature. This is supported by its distribution around Lake Sibaya where it forms a distinct and relatively narrow band (forming a marked tree line) surrounding the lake and pans, as well as other wetlands associated with the lake. To a lesser extent, *Acacia karroo* occupies a similar niche and is particularly prevalent in a narrow band between the lake and the Coastal Dune Forest.

Where elevation increases steeply Northern Coastal Forest occurs (often with only a narrow strip of *S. cordatum* or *A. karroo* between the forest and the lake), this being particularly noted along the dunes, which can be over 100m high but remain well vegetated with closed canopy woody species. The Northern Coastal Forest (which occurs around the lake and is distinct along the coastal dunes; Figure 4.1) has also been classified into two different forest types, namely Kwazulu-Natal Coastal Forest (particularly around the Western and Northern Zones) and Kwazulu-Natal Dune Forest (particularly between the ocean and the Main and Southern Basins) (von Maltitz *et al.* 2003). Coastal and Dune Forests are species rich units with several biogeographically important taxa, either due to Maputaland endemism or because their presence in Kwazulu-Natal represents the Southern limit of their distribution. They are also home to several protected species. It is recognised that the Dune Forests are affected by, and likely dependent on, salt spray brought inland from breaking waves by north-easterly winds (Breen 1979 and others in Allanson 1979). Zones where salt spray occurs are characterised by dense, low growing scrub but becoming closed canopy Dune Forest with increasing altitude and decreasing effects of salt spray.

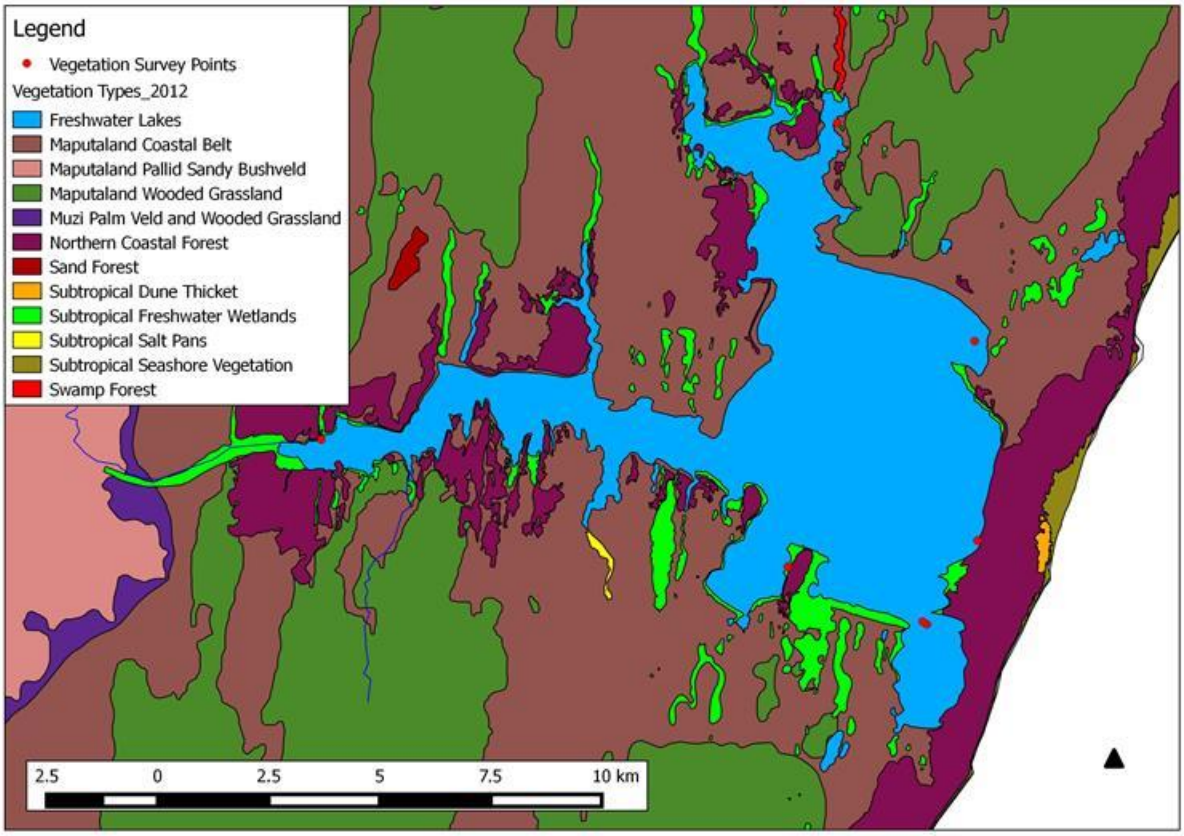


Figure 4.1 Map of general vegetation types surrounding Lake Sibaya

The Dune Forest associated with Lake Sibaya is a sensitive ecosystem (Breen 1979 in Allanson 1979) mainly due to its geographical location and sensitivity of non-scrub species to salt spray. If the scrub vegetation - which buffers the forest understory from salt spray - is disturbed, mortality of forest understory species may result with subsequent erosion of steep-sloped sand dunes. Dune Forest is difficult to rehabilitate to its natural state, and takes a long time to reach climax forest when opened.

There are localised areas of Swamp Forest associated with streams that flow into the Western Zone of the lake where waterlogged and marshy conditions persist. These forests are characterised by underlying peat-like humus and tall *Ficus trichopoda* and *S. cordatum* and are under threat from settlement expansion. Fragmentation of Swamp Forest by streamflow is also a potential threat with declining lake levels. This is supported by the observed mortality of *F. trichopoda* along the lake edge of the Southern Basin where lake levels have dropped by more than 5m.

Maputaland Wooded Grassland also occurs in the vicinity of the lake and its associated wetlands and generally occurs in flat areas of the coastal plain. This vegetation unit is characterised by coastal sandy grasslands rich in geoxylic suffrutices, dwarf shrubs, small trees and species rich herbaceous flora (Mucina & Rutherford 2006). It supports the endemic suffrutex form of *S. cordatum*. Interdune depression wetlands and hygrophilous grasslands occur in this area, but are excluded from this vegetation type. The hygrophilous grasslands are particularly important as grazing for hippos (Taylor, *pers. comm.*.).

Lake Sibaya and wetlands associated with it are recognised as National Freshwater Priority Areas (NFEPA; Nel *et al.* 2011). Numerous pans occur along the periphery of the lake (particularly along the Southern bank of the Western Arm and the Southwestern Basin) which may or may not be connected to the lake at higher water levels. Some of these areas were noted to be decanting water into the main lake and occurred at higher elevations that the main lake (in July 2015). Wetlands are characteristically surrounded by non-woody obligate plants (sedges, rushes and grasses) with a characteristic tree line at higher elevation (notably *S. cordatum*) and frequently with well-established aquatic flora.

The littoral zone of Lake Sibaya consists of submerged (aquatic) and emergent macrophytes with a distinct absence of woody species. Submerged vegetation is generally dense and extensive throughout the photic zone, which can vary but is generally from 0 to 7 m deep at Lake Sibaya. Areas that are exposed to higher wind levels and wave action tend to support lower densities of submerged macrophytes, but in more protected areas the percentage of areal cover is frequently 100% of the photic zone. Unfortunately the alien species *Myriophyllum spicatum* has become dominant in the submerged community. In areas where an influx of nutrients is prevalent, particularly in the vicinity of the water abstraction pump stations in the Western Arm and Southern Basin, some free floating species were noted. These included *Azolla filiculoides* and *Pistia stratiotes*, both of which are declared alien invasive weeds (Bromilow 2010).

The emergent macrophyte community is dominated by non-woody wetland obligate species arranged generally into two sub-communities. Species associated with protected areas and higher organic content substrata were dominated by *Typha capensis, Phragmites australis, Cyperus prolifer, C. papyrus, Hydrocotyle bonariensis, Ischaemum fasciculatum* and

Ludwigia octovalvis with some species forming mats extending over the water column (such as *Pycreus nitidus*). Species that dominate areas more exposed to wind and wave action included *Schoenoplectus scirpoides, Eleocharis acutangula, Cladium mariscus subsp. jamaicense* (particularly surrounding wetlands associated with the lake) and *Cyperus articulates.* Although *S. scirpoides* and *E. acutagula* are able to persist to depths of 2 m, they seldom grew beyond about 3 m from the water's edge even if it remained shallow. A few shoreline areas where wave and prevailing wind action is severe remain devoid of emergent macrophytes or they occurred in pockets and at lower densities.

The shoreline or "beach" macrophytes occur from the tree line to the emergent macrophytes, the length of which varies from place to place, and with varying density. The key feature is that the shoreline macrophytes are dominated by non-woody species (sedges and grasses), most of which are wetland obligates. Dominant species include *Andropogon eucomus, Cyperus natalensis, Dactyloctenium geminatum, Hemarthria altissima, Imperata cylindrica* and *Juncus oxycarpus.* At several sites woody encroachment is taking place, with the scattered occurrence of *S. cordatum* and *Casuarina equisetifolia* saplings or young adults. This is due to receding water levels and the extended lack of inundation stress along the shoreline that would maintain the area free of woody species.

4.3 Literature review

During the early to mid-Holocene Lake Sibaya was occupied by a saline lagoon which became increasingly isolated from the sea about 5030 years BP, since which time the lake has evolved to become a freshwater system with little sedimentation (Miller 1998). Sedimentation rates appear to have remained relatively constant over the last 250 years, despite recent land use change in the catchment (Humphries & Benitez-Nelson 2013).

The geology of the area consists of Quaternary and Tertiary sediments of the Maputaland group that mainly comprise unconsolidated and redistributed fine-grained sand (Watkeys *et al.* 1993). The morphology of the lake suggests that it comprises a series of drowned river valleys that developed when sea level was about 130 m lower than present levels (Humphries & Benitez-Nelson 2013). Winds are generally strong and tend to blow from the south and the north (Humphries & Benitez-Nelson 2013), while a rainfall gradient from east (1200 mm) to west (700 mm) is evident, but with an overall average of 900 mm per annum (Pitman & Hutchinson 1975; in Humphries & Benitez-Nelson 2013).

Lake Sibaya remains oligotrophic (Humphries & Benitez-Nelson 2013), even though studies have shown that in the western EWR zone, stratigraphic variations in total carbon, nitrogen and phosphorus increased abruptly to near-constant levels around the beginning of the 20th century, and appears to coincide with the onset of human settlement and land clearance in the catchment (Humphries & Benitez-Nelson 2013).

Neumann *et al.* (2008) used the palynology of two Holocene cores from the Western Arm of Lake Sibaya to show the sequence of vegetation, as well as the relationship between vegetation, climate and human impact over a period of roughly 6750-7100 years BP. These authors summarised the Lake Sibaya sequence by defining six pollen zones:

- the oldest of these, zone 6 or the *Phoenix-Isoglossa-Manilkara* Zone, about 5000-7700 years BP was dominated by an abundance of forest and savanna elements with *Podocarpus* and the Restionaceae also being common. Grass pollen, herbs, aquatics (except *Typha* and *Nymphaea*), swamp plants, ferns and algae were sparse or absent.
- Zone 5, the *Podocarpus-Ilex-monolete* Zone (about 1200-2000 years BP), was characterised by high pollen values for Poaceae, Haloragaceae, *Nymphaea*, *Persicaria* and monolete fern spores, with increasing values for the Cyperaceae. *Podocarpus, Morella, Ilex* and the Moraceae attain maximum counts but begin to decline within the represented time frame.
- Zone 4, the *Olea-Celtis* Zone (about 900-1200 years BP), was characterised by a peak of *Olea, Manilkara* and *Celtis*, although Poaceae were dominant and a sharp decrease of the monolete spores and *Podocarpus*.
- Zone 3, the *Phoenix-Hyphaene* Zone (about 500-900 years BP) was dominated by Poaceae and Cyperaceae were common, with a peak for *Phoenix, Hyphaene* and monolete spores. *Zea maysm m*ade its first appearance and *Pinus* pollen was found in low numbers.
- Zone 2, the *Spirostachys-Pinus* Zone (about 250-500 years BP), was dominated by Poaceae although these begin their decline, and *Pinus* rapidly increased. The zone was characterised by high values of *Spirostachys, Celtis, Stoebe* with *Manilkara* and *Rhus (Searsia)* increasing and *Sclerocarya* being common. The end of the zone is marked by sharp decreases in algae and Cyperacea pollen.
- Zone 1, the *Neophyte* Zone (from present to about 250 years BP), is characterised by a sharp decline in the Poaceae and the rise of neophytic trees such as *Ambrosia, Casuarina* and *Carya*. The Ericaceae and *Zea mays* are common and *Pinus* reaches a maximum, while the forest elements begin to decline.

Lake water levels fluctuate naturally on a seasonal basis (Allanson 1979; Bruton 1980), and the presence of underwater knickpoints and terraces indicate that lake level fluctuations have been common (Miller 1998). The distinct tree line that surrounds the lake appears to be consistent with the inundation levels when the lake is at its highest, roughly every decade.

Breen (1979; in Allanson 1979) describes the structure and maintenance of the Coastal Dune Forest that divides Lake Sibaya from the marine environment. He outlines the importance, high species diversity value and sensitivity of the Dune Forests as well as the difficulty of their rehabilitation. He also describes the critical role that wind and salt spray have in maintaining and structuring the Dune Forests. Lake water levels are important in that they limit the extent to which forest species can colonise. Inundation stress has resulted in a clearly defined tree line that surrounds the lake and beyond which, at low lake levels, none of the forest species are found. The exceptions are *Syzygium cordatum, Acacia karroo* and *Casuarina equisetifolia* which are able to encroach on sandy beaches at low lake levels. These phreatophytes however, are not really part of the Dune Forests, even though Breen includes *A. karroo* as a pioneer in areas where Dune Forest has been cleared.

Howard-Williams (1979; in Allanson 1979) discusses the distribution, biomass and role of aquatic macrophytes associated with Lake Sibaya and outlines community change between periods of high and low lake levels. He also outlines species composition within each of the distinct macrophyte communities associated with the lake. The most relevant summary of his work is that the primary determinants of lake-dependent macrophyte abundance and distribution are water depth (lake level), extent of the photic zone and exposure to wind and wave action.

4.4 Field survey

In July 2015 a field visit was undertaken to Lake Sibaya in order to broadly describe vegetation, to demarcate vegetation zonation and utilise a modified VEGRAI for the determination of the ecological status for demarcated zones (see section 4.5) and to survey and measure the hydraulic niche of plant species, vegetation zones and chosen indicators.

4.5 Description of the EWR zones in relation to vegetation

This section describes the expected reference and Present State of each EWR Zone. See Section 1.3 for a map (Figure 1.2) showing the location of the EWR zones and section 4.11 for a list of important plant species associated with the lake.

4.5.1 EWR Zone 1 – Southern Basin

4.5.1.1 Site location and Extent

The extent of the area included in the VEGRAI assessment of vegetation around the Southern Basin included a 500 m buffer around the basin. The vegetation assessment was based on a drive around the basin on the Southern side and two detailed field stops (Figure 4.2).

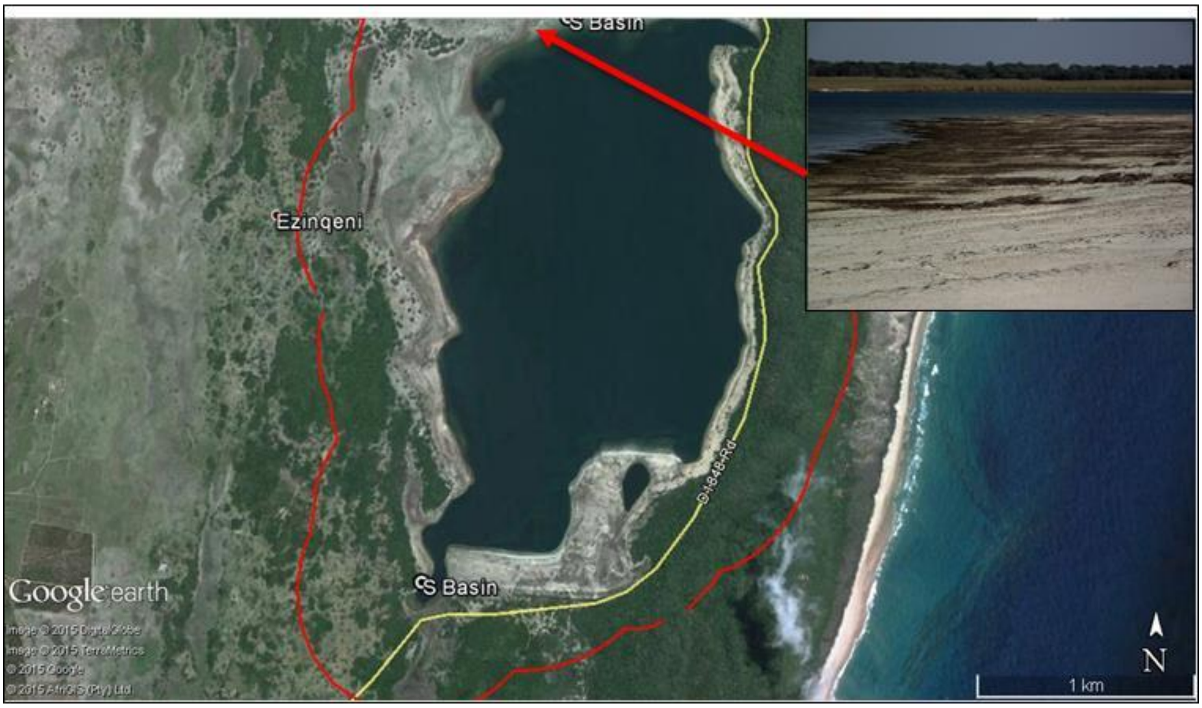


Figure 4.2 **Map showing the extent within which vegetation was assessed on the Southern Basin as well as sites used to ground-truth satellite data. The red line indicates a 500m wide buffer used to delineate the VEGRAI assessment. The inset shows dead and decaying *M. spicatum* along the lake edge (the former submerged zone)**

4.5.1.2 Reference State

The submerged aquatic zone is expected to be well developed, in keeping with lacustrine environments, with species distribution varying according to water clarity (which affects light penetration) and the degree of wind and wave disturbance. In shallow, more secluded areas Water Lilies (*Nymphaea nouchali var. caerulea*) and Broad-leaved Pondweed (*Potamogeton schweinfurthii*) are expected to be highly abundant, with Water Hornwort (*Ceratophyllum demersum var. demersum*) in still, deeper water. In more exposed areas where wind and wave action is more frequent and vigorous, the aquatic zone is more likely to be dominated by Fennel-leaved Pondweed (*Stuckenia pectinatus*) and Saw Weed (*Najas marina subsp. armata*). Spiked Water-milfoil (*Myriophyllum spicatum*), native to Europe, Asia and North Africa, is expected to be absent.

Emergent macrophytes in the littoral zone are expected to be well-developed in most sheltered areas not exposed to prevailing winds. Along most shores the dominant plant form is likely to be sedges and reeds, (notably *Schoenoplectus scirpoides, Phragmites australis* and *Eleocharis acutangula)* which should variously span the transition area from shoreline to the aquatic environment, growing well into the water and mixing with aquatic zone species. In sheltered areas, species more sensitive to wind and wave action (including *Typha capensis, Cyperus papyrus, C. prolifer, Ludwigia octovalvis* and *Hydrocotyle bonariensis*) should be abundant with 100% (or near 100%) areal coverage. Alien and woody species would be absent from this zone.

Shoreline macrophytes are those species that occur between the emergent macrophytes and the tree line and along open exposed beach areas where those occur. This zone should be dominated by a mixture of grasses and sedges (notably *C. natalensis, Juncus oxycarpus, Dactyloctenium geminatum* and *Imperata cylindrica*) and should be free of alien or woody species.

The tree line is where woody vegetation starts and should characteristically be in keeping with the surrounding vegetation type. This is mostly Northern Coastal [Dune] Forest but with some areas of Maputaland Coastal Belt. The beginning of this zone should remain clearly defined and usually indicates a level beyond which inundation is rare. Some encroachment of the shoreline zone by woody species is natural but should be transient and reduced by lake level fluctuations. This zone should be dominated by high woody cover and alien species should be absent.

4.5.1.3 Present State

The aquatic zone was more sparsely covered than the rest of the lake, and dominated by *S. pectinatus, P. sweinfurthii* and some *C. demersum. M. spicatum* was common but not dominant with a notable presence of dead aquatic plant material on open sandy areas.

The emergent macrophytes were represented by remnants of sedges (*C. mariscus, C. natalensis*) well away from the water's edge. Emergent macrophytes were absent at the water's edge in most places at the time of sampling, and analysis of historic satellite data has shown that the zone was not able to shift as water level declined (Figure 4.3).

Figure 4.3 Analysis of historic satellite data (Google Earth ©) showed that the emergent macrophyte zone did not shift, although there was an average rate of water level decline of 0.2 m/year

The shoreline vegetation was dominated by *C. natalensis, Juncus oxycarpus* and several grass species. Cover has been markedly reduced. There was evidence of woody encroachment into the zone (a sign of receding lake levels and the lack of inundation) with *C. equisetifolia* saplings and young adults noted low in the zone and where the water level was six years ago.

The tree line was clearly defined by large adult *S. cordatum* but numerous saplings of various ages were found within the shoreline vegetation, as well as invasion by *C. equisetifolia,* with some large specimens already established. This woody encroachment is probably due to receding lake levels and the absence of inundation stress which would keep the tree line in check as well as alien species invasion. Tree mortality, possibly due to receding water levels, was not observed except for a few *Ficus trichpoda* individuals that had succumbed to drought stress.

4.5.2 EWR Zone 2 – Main Basin

4.5.2.1 Site location and Extent

The extent of the area used for the VEGRAI assessment of vegetation around the Main Basin included a 500 m buffer around the basin, and was assessed based on a drive around the basin on the eastern and northern sides and three detailed field stops (Figure 4.4).

Figure 4.4 Map showing the extent within which vegetation was assessed on the Main Basin as well as sites used to ground-truth satellite data. The red line indicates a 500m wide buffer used to delineate the VEGRAI assessment. The inset (top) shows sparsity of emergent macrophytes in an exposed area. The inset (bottom) shows extension and composition of shoreline vegetation

4.5.2.2 Reference State

The Main Basin is characterised by more exposed, straighter shorelines than the other areas of the lake. As such submerged aquatic vegetation is expected to be less well represented and more generally dominated by species that are resilient to wind and wave action, such as Fennel-leaved Pondweed (*Stuckenia pectinatus*) and Saw Weed (*Najas marina subsp. armata*). Spiked Water-milfoil (*Myriophyllum spicatum*), native to Europe, Asia and North Africa, is expected to be absent.

Similarly, emergent macrophytes in the littoral zone are expected to be less well -developed as a result of exposure to prevailing wind and wave action. Along most shores the dominant plant form is likely to be sedges and grasses (notably *Schoenoplectus scirpoides, Juncus oxycarpus, Cyperus natalensis*) with coverage being lower with more exposure. Alien and woody species would be absent from this zone.

Shoreline macrophytes are those species that occur between the emergent macrophytes and the tree line and along open exposed beach areas where those occur. This zone should be dominated by a mixture of grasses and sedges (notably *C. natalensis, Juncus oxycarpus, Dactyloctenium geminatum* and *Imperata cylindrica*) and should be free of alien or woody species.

The tree line is where woody vegetation starts and should characteristically be in keeping with the surrounding vegetation type. There is some Maputaland Coastal Belt but mostly Northern Coastal Forest (specifically Dune Forest). The beginning of this zone should remain clearly defined and usually indicates a level beyond which inundation is rare. Some encroachment of the shoreline zone by woody species is natural (especially by *A. karroo*) but should be transient and reduced by lake level fluctuations. This zone should be dominated by high woody cover, notably *A. karoo, S. cordatum* and Dune Forest elements. *Casuarina equisetifolia* should be absent.

4.5.2.3 Present State

The aquatic zone was dominated by *S. pectinatus*, *N. marina and M. spicatum* although density was less than observed in the Northern and Western Arms, and depths of occurrence seemed to be less. The alien *M. spicatum* also seemed to dominate less than it did in quieter, more protected areas.

Emergent macrophytes were mostly sparse and were dominated by *S. scirpoides, C. natalensis* and *Cladium mariscus*. Alien and woody species were largely absent from the zone. Emergent macrophytes were generally found growing much higher above the water level than sheltered bays, and to less than 0.5 m below water level. The emergent macrophyte zone did not appear to be able to shift and alter species composition with changing lake levels as some of the other areas did. Satellite data (Google Earth ©) from 2006 and 2014 show lake levels at 17.58 and 15.77 mamsl respectively and the zone has not noticeably shifted, but has been depleted with only remnants of macrophyles remaining (Figure 4.5).

Figure 4.5 Analysis of historic satellite data (Google Earth ©) showed that the emergent macrophyte zone did not effectively shift, where water level declined up to 1.8m over 4 years i.e. an average rate of decline of 0.2 m/year

The shoreline vegetation was dominated by *C. natalensis*, several grass species (including *Andropogon eucomus* and *Imperata cylindrica*) and contained remnants of the emergent macrophytes (such as *C. mariscus*). Cover was about 50% but open sandy areas were evident, as was grazing. With receding lake levels this zone appears to be expanding, but it is likely that cover is decreasing due to water stress. There was evidence of woody encroachment into the zone (a sign of receding lake levels and the lack of inundation) with *S. cordatum* saplings noted in places in the upper area of the zone.

The tree line was clearly defined by large adult *S. cordatum* and *A. karroo* but numerous saplings of different age classes were found within the shoreline vegetation. This woody encroachment is likely due to receding lake levels and the absence of inundation stress which would keep the tree line in check. Tree mortality, possibly due to receding water levels, was not observed.

4.5.3 EWR Zone 3 – Northern Arm

4.5.3.1 Site location and Extent

The extent of the area used for the VEGRAI assessment of vegetation around the Northern Arm included a 500 m buffer around the arm, and was assessed based on a drive around the arm and one detailed field stop (Figure 4.6).

Figure 4.6 **Map showing the extent within which vegetation was assessed on the Northern Arm as well as sites used to ground-truth satellite data. The red line indicates a 500 m wide buffer used to delineate the VEGRAI assessment. The inset shows emergent macrophytes**

4.5.3.2 Reference State

The aquatic zone is expected to be well developed, in keeping with lacustrine environments, with species distribution varying according to water clarity (which affects light penetration) and the degree of wind and wave disturbance. In shallow, more secluded areas Water Lilies (*N. nouchali var. caerulea*) and Broad-leaved Pondweed (*P. schweinfurthii*) are expected to be highly abundant, with Water Hornwort (*C. demersum var. demersum*) in quiet deeper waters. In more exposed areas where wind and wave action is more frequent and vigorous, the aquatic zone is more likely to be dominated by Fennel-leaved Pondweed (*S. pectinatus*) and Saw Weed (*N. marina subsp. armata*). Spiked Water-milfoil (*M. spicatum*), native to Europe, Asia and North Africa, is expected to be absent.

Emergent macrophytes in the littoral zone are expected to be well developed in most areas not exposed to prevailing winds. Along most shores the dominant plant form is likely to be sedges and reeds, (notably *S. scirpoides, P. australis and E. acutangula*) which should variously span the transition area from shoreline to the aquatic environment, growing well into the water and mixing with aquatic zone species. In sheltered areas, species more sensitive to wind and wave action (including *T. capensis, C. papyrus, C. prolifer, L. octovalvis* and *H. bonariensis*) should be abundant with 100% (or near 100%) areal coverage. Alien and woody species would be absent from this zone.

Shoreline macrophytes should be dominated by a mixture of grasses and sedges (notably *C. natalensis, J. oxycarpus, D. geminatum* and *I. cylindrica*) and should be free of alien or woody species.

The tree line is where woody vegetation starts and should characteristically be in keeping with the surrounding vegetation type. This is mostly Maputaland Coastal Belt (with some district patches of Northern Coastal Forest). The beginning of this zone should remain clearly defined and usually indicates a level beyond which inundation is rare. Some encroachment of the shoreline zone by woody species is natural but should be transient and reduced by lake level fluctuations. This zone should be dominated by high woody areal cover, notably *S. cordatum.*

4.5.3.3 Present State

The submerged aquatic zone was dominated by Spiked Water-milfoil (*M. spicatum*), although all expected indigenous aquatic species remain present. Most of the Northern Arm is comprised of more sheltered areas where the aquatic zone was characterised by dense aquatic vegetation from near water level to depths of at least 2.5 m. Water Lilies and Broad-leaved Pondweed were common in shallow secluded areas growing in amongst emergent macrophytes or just beyond. Water Hornwort was present but not common and may be compromised by Spiked Water-milfoil.

Emergent macrophytes were dominated by S*. scirpoides, E. acutangula* and *Pycreus nitidus* along most of the shoreline of the Northern Arm, and by *T. capensis, P. australis, C. prolifer* and *L. octovalvis* in the more sheltered bay areas. *Pucreus nitidus* was found forming floating maps in more secluded areas. Alien and woody species were largely absent from the zone except for *M. spicatum* which overlaps from the aquatic environment. Vegetation cover is high (>80% areal cover) with little evidence of removal. Emergent macrophytes were generally found growing from 0.5 m above the water level to 1.5 m below water level (commonly) but as deep as 2.2 m. The emergent macrophyte zone appears to be able to shift and alter species composition with changing lake levels. Satellite data (Google Earth ©) from 2010 and 2014 show lake levels at 17.58 and 15.77 mamsl respectively and the zone has remained densely vegetated but has shifted longitudinally towards the declining water level (Figure 4.7). Mortality of *S. scirpoides* was seen above 0.4 m higher than water level in places.

December 2014 @ 15.77 mamsl

June 2010 @ 17.58 mamsl

Figure 4.7 Analysis of historic satellite data (Google Earth ©) showed that the emergent macrophyte zone can shift, up to 1.81 m in 4 years i.e. an average rate of decline of 0.36 m/year

The shoreline was dominated by *C. natalensis* and several grass species. Cover was high (>60% areal cover) but open sandy areas were evident and plant vigour was in keeping with the dry season. There was evidence of livestock using the area for grazing with well-developed pathways in some areas. With receding lake levels this zone appears to be expanding, but it's likely that cover is decreasing due to water stress. There was evidence of woody encroachment into the zone (a sign of receding lake levels and the lack of inundation) with *S. cordatum* saplings noted in places in the upper area of the zone.

The tree line was clearly defined by large adult S*. cordatum* but some saplings were found within the shoreline vegetation. This woody encroachment is likely due to receding lake levels and the absence of inundation stress which would keep the tree line in check. Tree mortality, possibly due to receding water levels, was not observed.

4.5.4 EWR Zone 4 – Southwestern Basin

4.5.4.1 Site location and Extent

The extent of the area used for the VEGRAI assessment of vegetation around the Southwestern Basin included a 500 m buffer around the basin, and was assessed based on a drive around the basin on the southerwestern side and a single detailed field stop (Figure 4.8).

Figure 4.8 Map showing the extent within which vegetation was assessed on the Southwestern basin as well as the site used to ground-truth satellite data. The red line indicates a 500 m wide buffer used to delineate the VEGRAI assessment. The inset shows shoreline and emergent macrophytes.

4.5.4.2 Reference State

The submerged aquatic zone is expected to be well developed, in keeping with lacustrine environments, with species distribution varying according to water clarity (which affects light penetration) and the degree of wind and wave disturbance. In shallow, more secluded areas Water Lilies (*N. nouchali var. caerulea*) and Broad-leaved Pondweed (*P. schweinfurthii*) are expected to be highly abundant, with Water Hornwort (*C. demersum var. demersum*) in quiet deeper waters. In more exposed areas where wind and wave action is more frequent and vigorous, the aquatic zone is more likely to be dominated by Fennel-leaved Pondweed (*S. pectinatus*) and Saw Weed (*N. marina subsp. armata*). Spiked Water-milfoil (*M. spicatum*), native to Europe, Asia and North Africa, is expected to be absent.

Emergent macrophytes in the littoral zone are expected to be well developed in most areas not exposed to prevailing winds. Along most shores the dominant plant form is likely to be sedges and reeds, (notably *S. scirpoides, P. australis and E. acutangula*) which should variously span the transition area from shoreline to the aquatic environment, growing well into the water and mixing with aquatic zone species. In sheltered areas, species more sensitive to wind and wave action (including *Typha capensis, Cyperus papyrus, C. prolifer,* *Ludwigia octovalvis* and *Hydrocotyle bonariensis*) should be abundant with 100% (or near 100%) areal coverage. Alien and woody species would be absent from this zone.

Shoreline macrophytes are those species that occur between the emergent macrophytes and the tree line and along open exposed beach areas where those occur. This zone should be dominated by a mixture of grasses and sedges (notably *C. natalensis, Juncus oxycarpus, Dactyloctenium geminatum* and *Imperata cylindrica*) and should be free of alien or woody species.

The tree line is where woody vegetation starts and should characteristically be in keeping with the surrounding vegetation type. There is mostly Maputaland Coastal Belt (with some distinct patches of Northern Coastal Forest). The beginning of this zone should remain clearly defined and usually indicates a level beyond which inundation is rare. Some encroachment of the shoreline zone by woody species is natural but should be transient and reduced by lake level fluctuations. This zone should be dominated by high woody cover, notably *S. cordatum*.

4.5.4.3 Present State

The submerged aquatic zone was dominated by Spiked Water-milfoil (*M. spicatum*), although all expected indigenous aquatic species remain present. Water lilies and Broad-leaved Pondweed were common in shallow secluded areas growing in amongst emergent macrophytes or just beyond. Water Hornwort was present but not common and may be compromised by Spiked Water-milfoil. *Nymphae nouchali var. caerulea* and *P. sweinfurthii* were found to depths of 1m below the water level, while *M. spictum* was found at 2.2 m.

Emergent macrophytes were dominated by *T. capensis, S. scirpoides and E. acutangula.* Alien and woody species were largely absent from the zone except for *M. spicatum* which overlaps from the aquatic environment. Vegetation cover is high (>80% areal cover) with little evidence of removal. Emergent macrophytes were generally found growing from 0.4 m above the water level to 1.6m below water level (commonly) but as deep as 2 m. The emergent macrophyte zone appears to be able to shift and alter species composition with changing lake levels. Satellite data (Google Earth ©) from 2006 and 2013 show lake levels at 17.58 and 16.11 mamsl respectively and the zone has remained densely vegetated but has shifted longitudinally towards the declining water level (Figure 4.9).

Figure 4.9 Analysis of historic satellite data (Google Earth ©) showed that the emergent macrophyte zone can shift, up to 1.5 m in 6 years i.e. an average rate of decline of 0.18 m/year

Shoreline macrophytes were dominated by *C. natalensis* and several grass species. Cover was high (>60% areal cover) but open sandy areas were evident and plant vigour was in keeping with the dry season. There was evidence of livestock using the area for grazing with well-developed pathways in some areas. With receding lake levels this zone appears to be expanding, but it is likely that cover is decreasing due to water stress. There was evidence of woody encroachment into the zone (a sign of receding lake levels and the lack of inundation) with *S. cordatum* saplings noted in places in the upper area of the zone.

The tree line was clearly defined by large adult *S. cordatum* but some saplings were found within the shoreline vegetation. This woody encroachment is likely due to receding lake levels and the absence of inundation stress which would keep the tree line in check. Tree mortality, possibly due to receding water levels, was not observed.

4.5.5 EWR Zone 5 – Western Arm

4.5.5.1 Site location and Extent

The extent of the area used for the VEGRAI assessment of vegetation around the Western Arm included a 500 m buffer around the arm, and was assessed based on a drive to the pump station at Mseleni, and a single detailed field stop (Figure 4.10).

Figure 4.10 Map showing the extent within which vegetation was assessed on the Western Arm as well as the site used to ground-truth satellite data. The red line indicates a 500 m wide buffer used to delineate the VEGRAI assessment. The inset shows shore vegetation in the foreground, followed by emergent macrophytes, and the clear tree line in the distance

4.5.5.2 Reference State

The aquatic zone is expected to be well developed, in keeping with lacustrine environments, with species distribution varying according to water clarity (which affects light penetration) and the degree of wind and wave disturbance. In shallow, more secluded areas Water Lilies (*N. nouchali var. caerulea*) and Broad-leaved Pondweed (*P. schweinfurthii*) are expected to be highly abundant, with Water Hornwort (*C. demersum var. demersum*) in quiet deeper waters. In more exposed areas where wind and wave action is more frequent and vigorous, the aquatic zone is more likely to be dominated by Fennel-leaved Pondweed (*S. pectinatus*) and Saw Weed (*N. marina subsp. armata*). Spiked Water-milfoil (*M. spicatum*), native to Europe, Asia and North Africa, is expected to be absent.

Emergent macrophytes in the littoral zone are expected to be well developed in most areas not exposed to prevailing winds. Along most shores the dominant plant form is likely to be sedges and reeds, (notably *S. scirpoides, P. australis and E. acutangula*) which should variously span the transition area from shoreline to the aquatic environment, growing well into the water and mixing with aquatic zone species. In sheltered areas, species more sensitive to wind and wave action (including *T. capensis, C. papyrus, C. prolifer, L.*

octovalvis and *H. bonariensis*) should be abundant with 100% (or near 100%) areal coverage. Alien and woody species would be absent from this zone.

Shoreline macrophytes should be dominated by a mixture of grasses and sedges (notably *C. natalensis, J. oxycarpus, D. geminatum* and *I. cylindrica*) and should be free of alien or woody species.

The tree line is where woody vegetation starts and should characteristically be in keeping with the surrounding vegetation type. There is mostly Maputaland Coastal Belt (with some district patches of Northern Coastal Forest). The beginning of this zone should remain clearly defined and usually indicates a level beyond which inundation is rare. Some encroachment of the shoreline zone by woody species is natural but should be transient and reduced by lake level fluctuations. This zone should be dominated by high woody cover, notably *S. cordatum.*

4.5.5.3 Present State

The submerged aquatic zone was dominated by Spiked Water-milfoil (*M. spicatum*), although all expected indigenous aquatic species remain present. Most of the Western Arm is comprised of more sheltered areas where the aquatic zone is likely characterised by dense aquatic vegetation from near water level to depths of at least 2.5 m. Water lilies and Broad-leaved Pondweed were common in shallow secluded areas growing in amongst emergent macrophytes or just beyond. Water Hornwort and Saw Weed were present but not common and may be compromised by Spiked Water-milfoil. Free-floating aliens (*A. filiculoides and P. stratiotes*) were present near the pump station.

Emergent macrophytes were dominated by *T. capensis, S. scirpoides* and *E. acutangula*. Alien and woody species were largely absent from the zone except for *M. spicatum* which overlaps from the aquatic environment. Vegetation cover is high (>80% areal cover) with little evidence of removal. Emergent macrophytes were generally found growing from 0.5 m above the water level to 1.5 m below water level (commonly) but as deep as 2.2 m. The emergent macrophyte zone appears to be able to shift and alter species composition with changing lake levels. Satellite data (Google Earth ©) from 2006, 2010 and 2014 show lake levels at 17.58, 16.66 and 16.11 mamsl respectively and the zone has remained densely vegetated but has shifted longitudinally towards the declining water level (Figure 4.11).

Jun 2013 @ 16.11 mamsl Nov 2010 @ 16.66 Jan 2006 @ 17.58 mamsl

Figure 4.11 Analysis of historic satellite data (Google Earth ©) showed that the emergent macrophyte zone can shift, up to 1.5 m in 3 years i.e. an average rate of decline of 0.18 m/year

Shoreline vegetation was dominated by *C. natalensis* and several grass species. Cover was high (>60% areal cover) but open sandy areas were evident and plant vigour was in keeping with the dry season. There was evidence of livestock using the area for grazing with well developed pathways in some areas and localised removal and disturbance around Mseleni. With receding lake levels this zone appears to be expanding, but it is likely that cover is decreasing due to water stress. There was evidence of woody encroachment into the zone (a sign of receding lake levels and the lack of inundation) with *S. cordatum* saplings noted in places in the upper area of the zone.

The tree line was clearly defined by large adult *S. cordatum* but some saplings were found within the shoreline vegetation. This woody encroachment is likely due to receding lake levels and the absence of inundation stress which would keep the tree line in check. Tree mortality, possibly due to receding water levels, was not observed.

4.6 EcoClassification of the Lake represented by the EWR Zones

VEGRAI level 4 (Kleynhans *et al.* 2007; modified) was used to determine the ecological status of wetland and riparian vegetation associated with Lake Sibaya. This included the littoral zone, the shore vegetation and the woody vegetation comprising a tree line surrounding the lake. Terrestrial vegetation units such as coastal and dune forests were however excluded from the VEGRAI assessment as they are not riparian, as were free floating macrophytes, which are not expected to change in response to changing water levels. At each site (Western and Northern Arms, Main, Southern and Southwestern Basins) a 500 m buffer area was delineated and woody vegetation integrity assessed within this area. The zones used for VEGRAI were the same as the selected DRIFT indicators i.e. submerged aquatic zone, emergent macrophyte zone, shore vegetation and non-forest woody vegetation surrounding the lake.

4.6.1 EWR Zone 1 – Southern Basin

4.6.1.1 Impacts at the Site

The Southern Basin was assessed on July 15th 2015. The primary impacts associated with the Southern Basin, which are the reason the PES has deviated from the reference state (natural or category A) are outlined in Table 4.1 (see section **Error! Reference source not found.** for definitions of ecological categories).

Table 4.1 The main impacts associated with the Southern Basin which cause the PES to deviate from the reference state (natural)

Component	Causes	Sources	Flow or non-flow related	Confidence
Vegetation	Altered species composition in the aquatic zone	Presence of *M. spicatum* in the aquatic zone	non-flow	5
	Altered species composition in the shoreline vegetation	Encroachment of zone by woody species including alien species (*S. cordatum* and *C. equisetifolia*)	flow	5
	Reduced non-woody cover in emergent macrophytes and shoreline vegetation	Thinning and mortality due to water stress from receding lake levels	flow	4

Confidence: 1 = low; 2 = low to medium; 3 = medium; 4 = medium to high; 5 = high

4.6.1.2 Reference Expectation versus Present Actual

The expected areal cover (%) for each vegetation component i.e. the envisioned general reference state compared to the actual estimated cover i.e. the assessed Present State, is shown in Table 4.2 for woody vegetation and Table 4.3 for non-woody vegetation for the Southern Basin.

Table 4.2 Expected cover (% areal) for different Woody vegetation components in different zones for reference state (REF) and actual cover as estimated in assessments (PES)

	Zone	**Woody Riparian**	**Woody Terrestrial**	**Non-woody**	**Perennial Alien**	**Open (Alluvium)**	**Open (Bedrock)**
REF	Submerged Macrophytes	0	0	100	0	0	0
	Emergent Macrophytes	0	0	100	0	0	0
	Shore Macrophytes	0	0	90	0	10	0
	Tree line	90	0	5	0	5	0
PES	Submerged Macrophytes	0	0	30	0	70	0
	Emergent Macrophytes	0	0	10	0	90	0
	Shore Macrophytes	0	5	50	0	45	0
	Tree line	80	0	5	10	5	0

Table 4.3 Expected cover (% areal) for different Non-woody vegetation components in different zones for reference state (REF) and actual cover as estimated in assessments (PES)

	Zone	**Reeds**	***Typha***	**Sedges**	**Forbs**	**Open**	**Grass**	**Low woody (<=50cm)**	**Aquatic**	**Alien**
REF	Submerged Macrophytes	5	5	5	5	0	5	0	75	0
	Emergent Macrophytes	10	25	40	10	0	10	0	5	0
	Shore Macrophytes	0	0	50	10	10	30	0	0	0
	Tree line	0	0	0	20	5	25	50	0	0
PES	Submerged Macrophytes	0	0	5	0	70	0	0	15	10
	Emergent Macrophytes	0	0	10	0	90	0	0	0	0
	Shore Macrophytes	0	0	25	5	45	15	10	0	0
	Tree line	0	0	5	10	35	10	40	0	0

4.6.1.3 Integrated PES

The overall integrated PES for the Southern Basin was 54.2%, which is a **category D** (largely modified; Table 4.4). Emergent macrophytes were depleted or absent due to decreasing lake levels and scored the worst (37.2%, category E). Similarly, shore vegetation was sparser than expected and scored 56.4% (category D), while submerged aquatic vegetation were dominated by an alien species with the resultant score of 45.8% (category D). Tree line vegetation was intact with the exception of mortality of localised *F. trichopoda* individuals, but woody encroachment of the shore vegetation was advanced and comprised mainly the alien *C. equisetifolia.* As a result, this zone scored a 79.4% (category B/C).

Table 4.4 Integration of zone scores (and categories) to produce an overall ecological score (54.2%) and category (D) for the Southern Basin

Level 4 Assessment		**Lake Sibaya (Southern Basin)**		**15 July 2015**	
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**
Submerged Macrophytes	45.8	7.1	3.0	1.0	0.5
Emergent Macrophytes	37.2	11.5	2.5	2.0	1.0
Shore Macrophytes	56.4	17.4	3.5	3.0	1.0
Tree line	79.4	18.3	3.3	4.0	0.8
Level 4 VEGRAI (%)				**54.2**	
VEGRAI EC				**D**	
Average Confidence				**3.1**	
	Submerged Macrophytes	Emergent Macrophytes	Shore Macrophytes	Tree line	
VEGRAI % (Zone)	45.8	37.2	56.4	79.4	
EC (Zone)	D	E	D	B/C	
Confidence (Zone)	3.0	2.5	3.5	3.3	

4.6.2 EWR Zone 2 – Main Basin

4.6.2.1 Impacts at the Site

The Main Basin was assessed on July 15th 2015. The primary impacts associated with the Main Basin, which are the reason the PES has deviated from reference state (natural or category A) are outlined in Table 4.5 (see section **Error! Reference source not found.** for definitions of ecological categories).

Table 4.5 The main impacts associated with the Main Basin which cause the PES to deviate from the reference state (natural)

Component	**Causes**	**Sources**	**Flow or non-flow related**	**Confidence**
Vegetation	Altered species composition in the aquatic zone	Prevalence of *M. spicatum* in aquatic zone	non-flow	5
	Reduced cover and abundance of emergent macrophytes	Receding lake levels combined with exposure to prevailing winds	flow	5
	Altered species composition in the shoreline vegetation	Encroachment of zone by woody species *(A. karroo and S. cordatum)*	flow	5

Confidence: 1 = low; 2 = low to medium; 3 = medium; 4 = medium to high; 5 = high

4.6.2.2 *Reference Expectation versus Present Actual*

The expected areal cover (%) for each vegetation component i.e. the envisioned general reference state compared to the actual estimated cover i.e. the assessed Present State, is shown in Table 4.6 for woody vegetation and Table 4.7 for non-woody vegetation for the Main Basin.

Table 4.6 Expected cover (% areal) for different Woody vegetation components in different zones for reference state (REF) and actual cover as estimated in assessments (PES)

	Zone	**Woody Riparian**	**Woody Terrestrial**	**Non-woody**	**Perennial Alien**	**Open (Alluvium)**	**Open (Bedrock)**
REF	Submerged Macrophytes	0	0	60	0	40	0
	Emergent Macrophytes	0	0	70	0	30	0
	Shore Macrophytes	0	0	80	0	20	0
	Tree line	70	0	10	0	20	0
PES	Submerged Macrophytes	0	0	40	0	60	0
	Emergent Macrophytes	0	0	40	0	60	0
	Shore Macrophytes	5	0	55	0	40	0
	Tree line	80	0	10	0	10	0

Table 4.7 Expected cover (% areal) for different Non-woody vegetation components in different zones for reference state (REF) and actual cover as estimated in assessments (PES)

	Zone	**Reeds**	***Typha***	**Sedges**	**Forbs**	**Open**	**Grass**	**Low woody (<=50cm)**	**Aquatic**	**Alien**
REF	Submerged Macrophytes	5	0	10	0	40	5	0	40	0
	Emergent Macrophytes	5	0	45	5	30	10	0	5	0
	Shore Macrophytes	0	0	30	10	20	40	0	0	0
	Tree line	0	0	5	10	20	45	30	0	0
PES	Submerged Macrophytes	0	0	5	0	60	0	0	15	20
	Emergent Macrophytes	0	0	30	5	60	0	0	5	0
	Shore Macrophytes	0	0	15	10	40	30	5	0	0
	Tree line	0	0	0	10	35	15	40	0	0

4.6.2.3 *Integrated PES*

The overall integrated PES for the Main Basin was 70.7%, which is a **category C** (moderately modified; Table 4.8).

Table 4.8 Integration of zone scores (and categories) to produce an overall ecological score (70.7%) and category (C) for the Main Basin

Level 4 Assessment		**Lake Sibaya (Southern Basin)**		**15 July 2015**	
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**
Submerged Macrophytes	77.5	11.9	3.5	1.0	0.5
Emergent Macrophytes	67.3	20.7	2.5	2.0	1.0
Shore Macrophytes	65.6	20.2	3.5	3.0	1.0
Tree line	77.7	17.9	3.3	4.0	0.8
Level 4 VEGRAI (%)				**70.7**	
VEGRAI EC				**C**	
Average Confidence				**3.2**	
	Submerged Macrophytes	Emergent Macrophytes	Shore Macrophytes	Tree line	
VEGRAI % (Zone)	77.5	67.3	65.6	77.7	
EC (Zone)	B/C	C	C	B/C	
Confidence (Zone)	3.5	2.5	3.5	3.3	

4.6.3 EWR Zone 3 – Northern Arm

4.6.3.1 Impacts at the Site

The Northern Arm was assessed on July 15th 2015. The primary impacts associated with the Northern Arm, which are the reason the PES has deviated from reference state (natural or category A) are outlined in Table 4.9 (see section **Error! Reference source not found.** for definitions of ecological categories).

Table 4.9 The main impacts associated with the Northern Arm which cause the PES to deviate from the reference state (natural)

Component	**Causes**	**Sources**	**Flow or non-flow related**	**Confidence**
Vegetation	Altered species composition in the aquatic zone	Dominance of aquatic zone *by M. spicatum*	non-flow	5
	Altered species composition in the shoreline vegetation	Encroachment of zone by woody species (*S. cordatum*)	flow	5
	Reduced non-woody cover in shoreline vegetation	Grazing and trampling pressure of livestock coupled with increasing water stress due to receding lake levels	both	3

Confidence: 1 = low; 2 = low to medium; 3 = medium; 4 = medium to high; 5 = high

4.6.3.2 Reference Expectation versus Present Actual

The expected areal cover (%) for each vegetation component i.e. the envisioned general reference state compared to the actual estimated cover i.e. the assessed Present State, is shown in Table 4.10 for woody vegetation and Table 4.11 for non-woody vegetation for the Northern Arm.

Table 4.10 Expected cover (%) for different woody vegetation components in different zones for reference state (REF) and actual cover as estimated in assessments (PES)

	Zone	**Woody Riparian**	**Woody Terrestrial**	**Non-woody**	**Perennial Alien**	**Open (Alluvium)**	**Open (Bedrock)**
REF	Submerged Macrophytes	0	0	100	0	0	0
	Emergent Macrophytes	0	0	100	0	0	0
	Shore Macrophytes	0	0	100	0	0	0
	Tree line	60	0	25	0	15	0
PES	Submerged Macrophytes	0	0	100	0	0	0
	Emergent Macrophytes	0	0	95	0	5	0
	Shore Macrophytes	5	0	85	0	10	0
	Tree line	45	0	35	0	20	0

Table 4.11 Expected cover (%) for different Non-woody vegetation components in different zones for reference state (REF) and actual cover as estimated in assessments (PES)

	Zone	**Reeds**	***Typha***	**Sedges**	**Forbs**	**Open**	**Grass**	**Low woody (<=50cm)**	**Aquatic**	**Alien**
REF	Submerged Macrophytes	5	5	10	5	0	5	0	70	0
	Emergent Macrophytes	5	15	60	5	0	10	0	5	0
	Shore Macrophytes	0	0	60	10	0	30	0	0	0
	Tree line	0	0	10	10	15	45	20	0	0
PES	Submerged Macrophytes	5	5	5	5	0	5	0	25	50
	Emergent Macrophytes	5	10	60	5	5	5	0	5	5
	Shore Macrophytes	0	0	40	10	15	30	5	0	0
	Tree line	0	0	5	10	50	15	20	0	0

4.6.3.3 Integrated PES

The overall integrated PES for the Northern Arm was 80.2%, which is a **category B/C** (somewhat modified; Table 4.12).

Table 4.12 Integration of zone scores (and categories) to produce an overall ecological score (80.2%) and category (B/C) for the Northern Arm

Level 4 Assessment		**Lake Sibaya (Southern Basin)**		**15 July 2015**	
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**
Submerged Macrophytes	65.0	10.0	3.5	1.0	0.5
Emergent Macrophytes	90.0	27.7	2.5	2.0	1.0
Shore Macrophytes	80.0	24.6	3.5	3.0	1.0
Tree line	77.7	17.9	3.3	4.0	0.8
Level 4 VEGRAI (%)				**80.2**	
VEGRAI EC				**B/C**	
Average Confidence				**3.2**	
	Submerged Macrophytes	Emergent Macrophytes	Shore Macrophytes	Tree line	
VEGRAI % (Zone)	65.0	90.0	80.0	77.7	
EC (Zone)	C	A/B	B/C	B/C	
Confidence (Zone)	3.5	2.5	3.5	3.3	

4.6.4 EWR Zone 4 – Southwestern Basin

4.6.4.1 Impacts at the Site

The Southwestern basin was assessed on July 16th 2015. The primary impacts associated with the Southwestern basin, and which are the reason the PES has deviated from reference state (natural or category A) are outlined in Table 4.13 (see section **Error! Reference source not found.** for definitions of ecological categories).

Table 4.13 The main impacts associated with the Southwestern Basin which cause the PES to deviate from the reference state (natural)

Component	**Causes**	**Sources**	**Flow or non-flow related**	**Confidence**
Vegetation	Altered species composition in the aquatic zone	Dominance of aquatic zone *by M. spicatum*	non-flow	5
	Altered species composition in the shoreline vegetation	Encroachment of zone by woody species (*S. cordatum*)	flow	5
	Reduced non-woody cover in shoreline vegetation	Likely thinning due to water stress from receding lake levels	flow	3

Confidence: 1 = low; 2 = low to medium; 3 = medium; 4 = medium to high; 5 = high

4.6.4.2 Reference Expectation versus Present Actual

The expected areal cover (%) for each vegetation component i.e. the envisioned general reference state compared to the actual estimated cover i.e. the assessed Present State, is shown in Table 4.14 for woody vegetation and Table 4.15 for non-woody vegetation for the Southwestern basin.

Table 4.14 Expected cover (% areal) for different Woody vegetation components in different zones for reference state (REF) and actual cover as estimated in assessments (PES)

	Zone	**Woody Riparian**	**Woody Terrestrial**	**Non-woody**	**Perennial Alien**	**Open (Alluvium)**	**Open (Bedrock)**
REF	Submerged Macrophytes	0	0	100	0	0	0
	Emergent Macrophytes	0	0	100	0	0	0
	Shore Macrophytes	0	0	90	0	10	0
	Tree line	70	0	15	0	15	0
PES	Submerged Macrophytes	0	0	100	0	0	0
	Emergent Macrophytes	0	0	100	0	0	0
	Shore Macrophytes	5	0	75	0	20	0
	Tree line	50	0	30	0	20	0

Table 4.15 Expected cover (% areal) for different Non-woody vegetation components in different zones for reference state (REF) and actual cover as estimated in assessments (PES)

	Zone	**Reeds**	***Typha***	**Sedges**	**Forbs**	**Open**	**Grass**	**Low woody (<=50cm)**	**Aquatic**	**Alien**
REF	Submerged Macrophytes	5	5	5	5	0	5	0	75	5
	Emergent Macrophytes	10	25	40	10	0	10	0	5	10
	Shore Macrophytes	0	0	50	10	10	30	0	0	0
	Tree line	0	0	10	10	15	35	30	0	0
PES	Submerged Macrophytes	5	10	10	5	0	0	0	25	45
	Emergent Macrophytes	5	25	45	10	0	5	0	5	5
	Shore Macrophytes	0	0	35	10	20	30	5	0	0
	Tree line	0	0	5	10	30	25	30	0	0

4.6.4.3 Integrated PES

The overall integrated PES for the Northern Arm was 80.1%, which is a **category B/C** (somewhat modified;

Table 4.16).

Table 4.16 Integration of zone scores (and categories) to produce an overall ecological score (80.1%) and category (B/C) for the Southwestern Basin

Level 4 Assessment		**Lake Sibaya (Southern Basin)**		**15 July 2015**	
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**
Submerged Macrophytes	69.2	10.6	3.5	1.0	0.5
Emergent Macrophytes	87.2	26.8	2.5	2.0	1.0
Shore Macrophytes	77.1	23.7	3.5	3.0	1.0
Tree line	81.7	18.8	3.3	4.0	0.8
Level 4 VEGRAI (%)				**80.1**	
VEGRAI EC				**B/C**	
Average Confidence				**3.2**	
	Submerged Macrophytes	Emergent Macrophytes	Shore Macrophytes	Tree line	
VEGRAI % (Zone)	69.2	87.2	77.1	81.7	
EC (Zone)	C	B	C	B/C	
Confidence (Zone)	3.5	2.5	3.5	3.3	

4.6.5 EWR Zone 5 – Western Arm

4.6.5.1 Impacts at the Site

The Western Arm was assessed on July 16th 2015. The primary impacts associated with the Western Arm, and which are the reason the PES has deviated from reference state (natural or category A) are outlined in Table 4.17 (see section **Error! Reference source not found.** for definitions of ecological categories).

Table 4.17 The main impacts associated with the Western Arm which cause the PES to deviate from the reference state (natural)

Component	**Causes**	**Sources**	**Flow or non-flow related**	**Confidence**
Vegetation	Altered species composition in the aquatic zone	Dominance of aquatic zone *by M. spicatum*	non-flow	5
	Altered species composition in the shoreline vegetation	Encroachment of zone by woody species (*S. cordatum*)	flow	5
	Reduced non-woody cover in shoreline vegetation and woody vegetation beyond tree line	Agricultural activities and human pressure	non-flow	3

Confidence: 1 = low; 2 = low to medium; 3 = medium; 4 = medium to high; 5 = high

4.6.5.2 Reference Expectation versus Present Actual

The expected areal cover (%) for each vegetation component i.e. the envisioned general reference state compared to the actual estimated cover i.e. the assessed Present State, is shown in Table 4.18 for woody vegetation and Table 4.19 for non-woody vegetation for the Western Arm.

Table 4.18 Expected cover (% areal) for different Woody vegetation components in different zones for reference state (REF) and actual cover as estimated in assessments (PES)

	Zone	**Woody Riparian**	**Woody Terrestrial**	**Non-woody**	**Perennial Alien**	**Open (Alluvium)**	**Open (Bedrock)**
REF	Submerged Macrophytes	0	0	100	0	0	0
	Emergent Macrophytes	0	0	100	0	0	0
	Shore Macrophytes	0	0	90	0	10	0
	Tree line	70	0	15	0	15	0
PES	Submerged Macrophytes	0	0	100	0	0	0
	Emergent Macrophytes	0	0	100	0	0	0
	Shore Macrophytes	5	0	75	0	20	0
	Tree line	45	0	35	0	20	0

Table 4.19 Expected cover (% areal) for different Non-woody vegetation components in different zones for reference state (REF) and actual cover as estimated in assessments (PES).

	Zone	**Reeds**	***Typha***	**Sedges**	**Forbs**	**Open**	**Grass**	**Low woody (<=50cm)**	**Aquatic**	**Alien**
REF	Submerged Macrophytes	5	5	10	5	0	5	0	70	0
	Emergent Macrophytes	10	25	40	10	0	10	0	5	0
	Shore Macrophytes	0	0	50	10	10	30	0	0	0
	Tree line	0	0	10	10	15	35	30	0	0
PES	Submerged Macrophytes	5	10	10	0	0	0	0	20	55
	Emergent Macrophytes	5	40	35	5	0	5	0	5	5
	Shore Macrophytes	0	0	35	10	20	30	5	0	0
	Tree line	0	0	5	10	30	25	30	0	0

4.6.5.3 Integrated PES

The overall integrated PES for the Western Arm was 77.2%, which is a **category C** (moderately modified;

Table 4.20).

Table 4.20 Integration of zone scores (and categories) to produce an overall ecological score (77.2%) and category (C) for the Western Arm

Level 4 Assessment		**Lake Sibaya (Southern Basin)**		**15 July 2015**	
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**
Submerged Macrophytes	65.0	10.0	3.5	1.0	0.5
Emergent Macrophytes	87.2	26.8	2.5	2.0	1.0
Shore Macrophytes	77.1	23.7	3.5	3.0	1.0
Tree line	72.2	16.7	3.3	4.0	0.8
Level 4 VEGRAI (%)				**77.2**	
VEGRAI EC				**C**	
Average Confidence				**3.2**	
	Submerged Macrophytes	Emergent Macrophytes	Shore Macrophytes	Tree line	
VEGRAI % (Zone)	65.0	87.2	77.1	72.2	
EC (Zone)	C	B	C	C	
Confidence (Zone)	3.5	2.5	3.5	3.3	

4.7 Hydraulic Niche of Indicator Plant Species

The mean measurement of the hydraulic niche of plant species relative to lake level is shown in Table 4.21 for lower limits and Table 4.22 for upper limits, with ranges shown in Table 4.23 (raw data is provided in section 4.13).

Table 4.21 Mean lower limits (m) of indicator species expressed as height above or depth below water level (at the respective site)

Species / Indicator	Growth Form	Main Basin	Main Basin (link)	Northern Arm	Southern Basin	SW Basin	Western Arm
Andropogon eucomus	Sbm		0.87			0.62	
Casuarina equisitifolia	Wv				3.32		
Casuarina equisitifolia_sapling	Wv		0.97		2.32		
Cladium mariscus subsp. Jamaicense	Em		0.56				
Cyperus articulates	Em					-0.15	
Cyperus natalensis	Sbm		0.26	1.97	2.01		
Eleocharis acutangula	Em	-1.50		-1.08			
Hydrocotyle bonariensis	Em					-0.10	
Juncus oxycarpus	Sbm	-0.15			2.01		
Ludwigia octovalvis	Em			-0.60		-0.50	
Myriophyllum spicatum	sam			-2.05			-1.35
Nymphaea nouchalia	sam			-1.83		-0.68	-0.65
Phragmites australis	Em		0.85				
Potamogeton schweinfurthii	sam		-0.30	-1.20		-0.80	
Pycreus nitidus	Em					-0.10	
Pycreus polystachyos var. polystachyos	Em		0.11				
Schoenoplectus scirpoides	Em		-0.17	-1.59		-2.20	-1.30
Stuckenia pectinatus			-0.30				
Syzygium cordatum	Wv			5.86	4.84	4.32	
Typha capensis	Em		-0.88	-0.74		-1.00	-0.65

Sbm = Shore “beach” macrophytes

Em = Emergent macrophytes

Sam = Submerged aquatic macrophytes

Wv = Woody “lake-dependent” vegetation

Table 4.22 Mean upper limits (m) of indicator species expressed as height above or depth below water level (at the respective site)

Species / Indicator	Growth Form	Main Basin	Main Basin (link)	Northern Arm	Southern Basin	SW Basin
Cladium mariscus subsp. jamaicense	Em		0.94			
Cyperus articulatus	Em					0.20
Cyperus natalensis	sbm		0.98	4.86		3.82
Eleocharis acutangula	Em			-0.43		
Juncus oxycarpus	sbm				2.32	
Ludwigia octovalvis	Em			0.40		
Myriophyllum spicatum	Sam			0.00		-0.45
Nymphaea nouchalia	Sam			-0.15		0.00
Phragmites australis	Em		1.48			
Potamogeton schweinfurthii	Sam			-0.20		-0.20

Species / Indicator	Growth Form	Main Basin	Main Basin (link)	Northern Arm	Southern Basin	SW Basin
Schoenoplectus scirpoides	Em		0.78	0.18		0.23
Schoenoplectus scirpoides_dead	Em		0.85			0.43
Stuckenia pectinatus	Sam	0.00				
Typha capensis	Em		0.90			

Sbm = Shore "beach" macrophytes

Em = Emergent macrophytes

Sam = Submerged aquatic macrophytes

Wv = Woody "lake-dependent" vegetation

Table 4.23 The hydraulic range of indicator species expressed as height above or depth below water level

Species	Min level (m)	Max level (m)
Andropogon eucomus	0.62	0.87
Casuarina equisitifolia	3.32	3.32
Cladium mariscus subsp. jamaicense	0.46	0.94
Cyperus articulatus	-0.15	0.20
Cyperus natalensis	0.26	4.86
Eleocharis acutangula	-1.50	0.00
Hydrocotyle bonariensis	-0.10	0.40
Juncus oxycarpus	-0.15	2.32
Ludwigia octovalvis	-0.60	0.40
Myriophyllum spicatum	-2.21	0.00
Nymphaea nouchalia	-1.83	0.00
Phragmites australis	0.85	1.48
Potamogeton schweinfurthii	-1.20	-0.20
Pycreus nitidus	-0.10	0.30
Pycreus polystachyos var. polystachyos	0.11	0.11
Schoenoplectus scirpoides	-2.28	0.78
Stuckenia pectinatus	-0.30	0.00
Syzygium cordatum	4.32	5.86
Typha capensis	-1.20	0.90
Schoenoplectus scirpoides (dead)	0.43	0.85
Syzygium cordatum (sapling)	3.54	3.54
Myriophyllum spicatum (dead about 3 years ago)	0.87	0.87
Myriophyllum spicatum (dead about 5 years ago)	1.42	1.42
Casuarina equisitifolia (sapling)	0.97	2.32

4.8 Identification of vegetation indicators

4.8.1 Indicator list for vegetation

A list of species/guilds and their reason for selection as indicators in the EWR assessments is given in Table 4.24. Their expected responses to water level changes are outlined in Table 4.25. Details of species within each guild are shown in section 4.12.

Table 4.24 Indicators and reasons for their selection

Indicator	**Reasons for selection as indicator**
Free floating vegetation	Alien free floating species were found at the pumping stations on the Western Arm and Southern Basin and although they are likely independent of lake level, they may pose a problem if nutrient concentrations were to be affected by changing water levels.
Submerged aquatic macrophytes	Integral and dominant component of the lake and important for habitat and food source for other lake components.
Emergent macrophytes	Zonation clearly evident and narrowly associated with water's edge. Also provide feeding, habitat and nursery areas for other lake components.
Shore "beach" macrophytes	Extensive and clearly zoned. Important for stabilizing sand which would otherwise be blown in prevailing winds.
Woody "lake-dependent" vegetation	Comprises phreatophytic species with clear zonation indicating decadal inundation. Encroachment likely under declining lake levels.
Wetlands and Pans associated with the lake	Extensive, protected by legislation, provide breeding and feeding for other lake components.
Swamp Forest	Sensitive and protected. Links to lake tenuous and is more influenced by clearing for agricultural activities.

Table 4.25 List of vegetation indicators and their predicted direction of response to water level changes

Indicator	**Definition**	**Predicted change**	**References**
Free floating vegetation	Macrophyte, free floating, not rooted	Independent, but dependent on nutrients	
Submerged aquatic macrophytes	Macrophyte, submerged, aquatic	Can shift if decline is slow and slope remains gentle; also dependent on photic zone depth	Allanson 1979
Emergent macrophytes	Macrophyte, wetland obligate, hydrophyte, helophyte, includes sudd hydrophytes	Can shift if decline remains slow, but mostly only in protected (wind, wave) areas	Measured from historic satellite data (Google Earth ©); Allanson (1979) describes species compositional changes high and low lake levels.
Shore "beach" macrophytes	Macrophytes, non-woody, wetland obligates	May shift but more likely to reduce in density as extent increases	Allanson (1979) describes species compositional changes high and low lake levels.
Woody "lake-dependent" vegetation	Phreatophytic trees	Will encroach into shore zone, in extreme cases mortality may occur	Lite and Stromberg 2005

Indicator	Definition	Predicted change	References
Wetlands and Pans associated with the lake	Temporary to permanently wet areas dominated by non-woody, wetland obligate macrophytes	Loss of integrity, condition and functionality as lake levels decline	
Swamp Forest	Designated forest typified by Ficus trichopoda	Desiccation with declining levels	

4.8.2 Description and location of indicators

A description and location of indicator guilds used to represent vegetation associated with the Lake are given in Table 4.26.

Table 4.26 Indicator guilds used to represent vegetation associated with Lake Sibaya

Indicator	Description	Location
Free floating vegetation	Macrophyte, free floating, not rooted, includes Red Azolla (Water Fern) and Water Lettuce	Currently confined to the Western Arm and Southern Basin near the pump stations, and in protected “bays”.
Submerged aquatic macrophytes	Macrophyte, submerged, aquatic, rooted, includes Water Hornwort, Saw Weed, Blue Water Lily, Broad-leaved Pondweed, Fennel-leaved Pondweed	Almost completely surrounds the lake edge below water level up to 7 m deep, but less dense where wave action is severe.
Emergent macrophytes	Macrophyte, wetland obligate, hydrophyte, helophyte, includes sudd hydrophytes, represented by Saw Grass, Jointed Flat Sedge, Papyrus, Dwarf Papyrus, Water Pennywort, Hippo Grass, Shrubby Ludwigia, Common Reed, Bulrush.	Forms a narrow fringe around the lake and extends variously into the water, but up to 2 m. Sub-communities exist and depend on degree of protection from wind and wave action and substrate organic content.
Shore “beach” macrophytes	Macrophytes, non-woody, wetland obligates, includes Snowflake Grass, Swamp Coach, Cottonwool Grass, sedges	Vegetates the sandy shores from the emergent macrophytes fringe to the tree line. Density and species composition may vary with degree of exposure to wind disturbance and water stress.
Woody “lake-dependent” vegetation	Phreatophytic trees, including Sweet Thorn, Waterberry, Horsetail Tree and Guava	Forms a clearly define boundary at or near the lake level when it is highest (roughly every 10 years), but encroaches into shore vegetation during low lake levels.
Wetlands and Pans associated with the lake	Temporary to permanently wet areas dominated by non-woody, wetland obligate macrophytes	Variously associated with the Lake and some connected when lake levels are high. Surrounded by same woody vegetation as described above.
Swamp Forest	Designated forest typified by Swamp Fig (Ficus trichopoda)	Limited to extremes of the western and Northern Arms, level of degradation high due to clearing and agricultural activities.

Indicator	Description	Location
Dune Forest	Well defined, well documented (Mucina & Rutherford 2006), dense Forest up to 100m high, with several important and protected species	Between the Lake and the marine environment, assumed to be largely independent of lake level.

4.8.3 Linked indicators

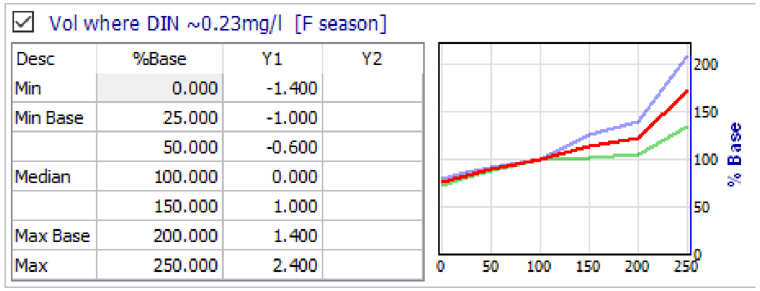
The linked indicators used in DRIFT to model water requirements of vegetation are motivated in Table 4.27.

Table 4.27 Linked indicators and motivation representing vegetation response

Indicator	Linked indicator	Motivation
Free floating vegetation	Nitrogen	The abundance of free floating vegetation is limited by nutrient availability, especially in oligotrophic systems.
Submerged aquatic macrophytes	Rate of change in water level	The indicator is dynamic and can shift if the rate of change is slow enough and habitat remains available.
	Area of 0-7m deep	Represents the photic zone, which is also the area potentially available area for colonisation
Emergent macrophytes	Wetted perimeter	Represents the extent of potentially available habitat for the indicator.
	Area between 0.65 below and 0.3m above water level	Represents the area of high density and frequent occurrence of the indicator.
	Area from 1.5-2m deep	Represents deeper areas that the indicator may also occupy.
	Rate of change in water level	The indicator is dynamic and can shift if the rate of change is slow enough and habitat remains available.
Shore “beach” macrophytes	Area of shore between 0.6m and 3.8m above water level	Represents the habitable area of the indicator where frequency and density are highest.
	Rate of change in water level	The indicator may be able to persist if the rate of change is slow enough and habitat remains available.
Woody “lake-dependent” vegetation	Area exposed below 20.39 mamsl (beach)	Represents the area where the indicator my encroach in the absence of inundation
	Vertical distance from water level (to fixed tree line)	Represents the phreatophytic zone which is linked to survival.
	Rate of change in water level	The indicator may be able to persist if the rate of change is slow enough and habitat remains available.
Wetlands and Pans associated with the lake	Vertical distance from water level (to fixed tree line)	Since these habitats are dependent on rainfall and ground water, the vertical distance to moisture is linked to wetland / pan condition.
Swamp Forest	Vertical distance from water level (to fixed tree line)	Represents the phreatophytic zone which is linked to survival.

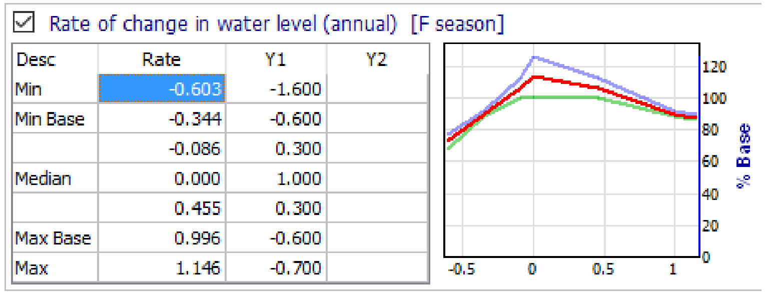
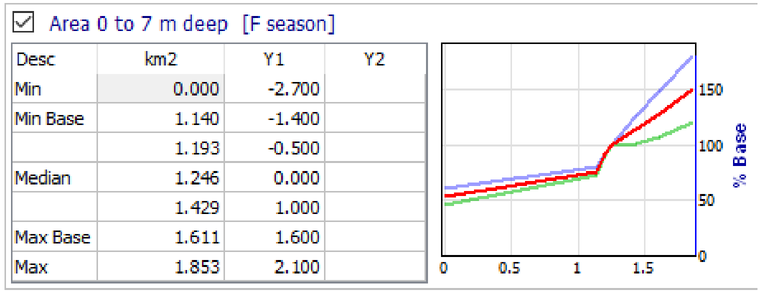
4.9 Motivations for response curves

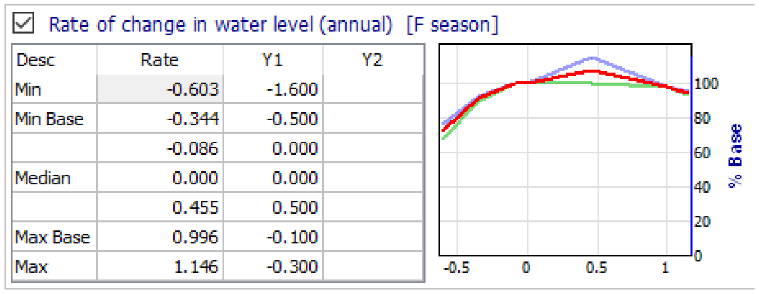
4.9.1 EWR Zone 1 – Southern Basin

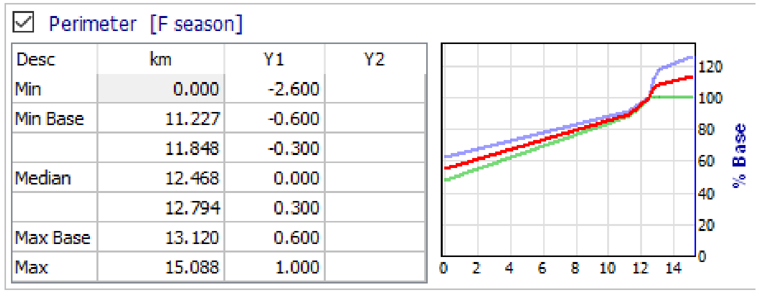
Free floating Vegetation		
Response curve	Explanation	Confidence
	It is assumed that there will not be concentration changes related to lake level (see water quality rationale) but that flushes of nutrients entering the lake are localised and non-flow related and will not alter the oligotrophic nature of the lake. Concentrations were found to be higher however in shallower water (up to 2m in depth) and this value of 0.23mg/l was used here as an indicator rather than the lower value on 0.07mg/l for deeper water. Since growth of *Azolla* and *Pistia* is possible at these levels of nutrients it is assumed that free floating vegetation has to potential to increase if the volume of water with these levels of nutrients also increases.	3

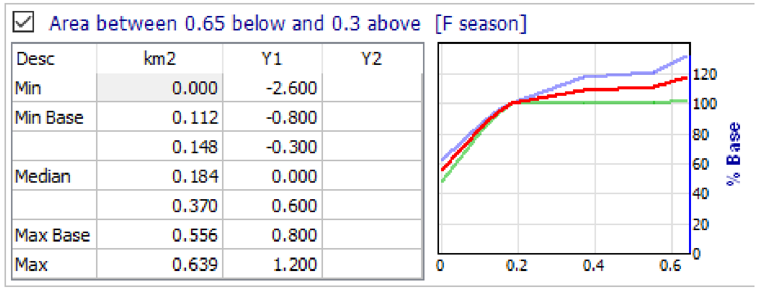
☑ Vol where DIN ~0.23mg/l [F season]

Desc	%Base	Y1	Y2
Min	0.000	-1.400	
Min Base	25.000	-1.000	
	50.000	-0.600	
Median	100.000	0.000	
	150.000	1.000	
Max Base	200.000	1.400	
Max	250.000	2.400	

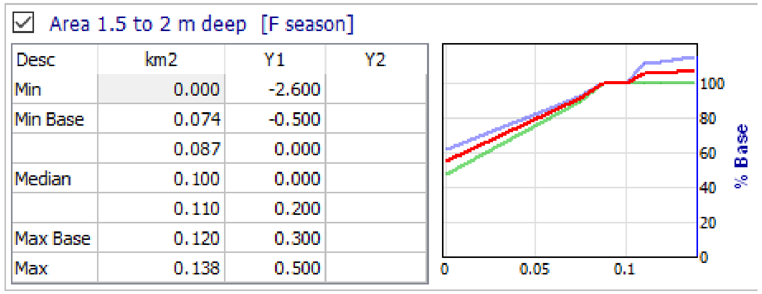
<table>
<tr><td colspan="2">Submerged Aquatic Macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.600</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.300</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>1.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>-0.600</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-0.700</td><td></td></tr>
</table>
</td><td>It is likely that submerged macrophytes as a zone (0 to -7m water depth) will be able to shift relatively rapidly (within a growing season) if the rate of change in water level is slow. [<i>Myriophyllum spicatum</i> for example is able to achieve root growth rates of up to 1cm/day (Hussner <i>et al</i>. 2009)]. Conversely, the width of the zone is likely to shrink if rates of change are faster than the ability of plants to colonise newly available habitat. The critical rate of change of water level has been arbitrarily set at 0.5m per year. Rapid inundation to 0.5m is likely to result in a rapid increase in growth, but inundation beyond 1m is likely to reduce it. [Zhang <i>et al</i>. (2015) showed that the amplitude of water level fluctuation was the major determinant of M. spicatum biomass in various floodplain lakes].</td><td>4</td></tr>
<tr><td>
☑ Area 0 to 7 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.700</td><td></td></tr>
<tr><td>Min Base</td><td>1.140</td><td>-1.400</td><td></td></tr>
<tr><td></td><td>1.193</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>1.246</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.429</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>1.611</td><td>1.600</td><td></td></tr>
<tr><td>Max</td><td>1.853</td><td>2.100</td><td></td></tr>
</table>
</td><td>Allanson (1979) found submerged macrophytes fringing the lake from depths of 1m to 7m and at this time the 1% level for white light was at 12m. Previously submerged macrophytes were found at depths of 9 to 12m (Boltt <i>et al</i>. 1969; Hill <i>et al</i>. 1975 in Bruton & Cooper 1980). When turbidity increased during high water levels however, submerged macrophytes were only found to depths of 5.5m and photosynthetically active radiation to 7 to 8m (Allanson 1979). During the field visit in July 2015 submerged macrophytes were found to occur from the water's edge to at least 2.5m, but it was not possible to sample greater depths. The relationship of submerged macrophytes to habitable area (0-7m depth, depending on turbidity) is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>4</td></tr>
</table>

<table>
<tr><th colspan="2">Emergent Macrophytes</th><th></th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>

☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.600</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>-0.100</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-0.300</td><td></td></tr>
</table>

</td><td>Water level fluctuations were superimposed on satellite data (Google Earth) and related to emergent macrophyte zone integrity. Data showed that in exposed areas a rate of water level decline of 0.2m/year [or more] was associated with emergent macrophytes that were not able to track the declining shift in water level. In sheltered areas however, emergent macrophytes were able to shift with declining water level, up to a rate of 0.36m/year. Sample size was limited however which severely retards a better understanding of the exact relationship. Rapid inundation to 0.5m is likely to result in a rapid increase in growth, but inundation beyond 1m is likely to reduce it.</td><td>4</td></tr>
<tr><td>

☑ Perimeter [F season]
<table>
<tr><th>Desc</th><th>km</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>11.227</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>11.848</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>12.468</td><td>0.000</td><td></td></tr>
<tr><td></td><td>12.794</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>13.120</td><td>0.600</td><td></td></tr>
<tr><td>Max</td><td>15.088</td><td>1.000</td><td></td></tr>
</table>

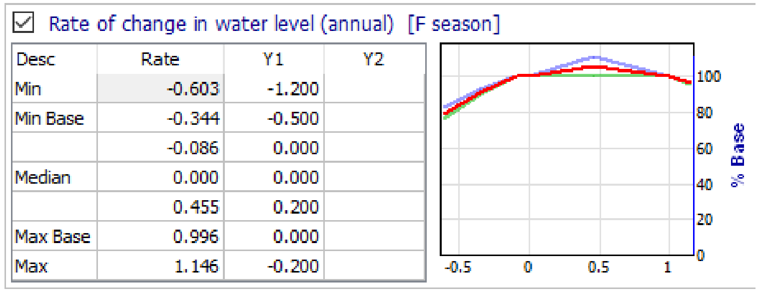
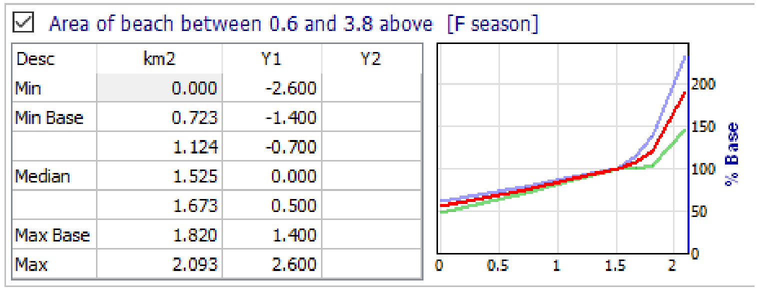
</td><td>The wetted perimeter represents an area of potentially available habitat for emergent macrophytes which were found to be variously present from 40cm above water level to depths of 2.2m in July 2015. Furthermore, analyses of current and historic satellite data (Google Earth (C)) revealed that emergent macrophytes, as a zone, could shift as the water's edge did (from January 2006 through November 2010 to June 2013) i.e. small shifts in a little as 3 years. The ability of emergent macrophytes to shift in accordance with lake level will depend on the rates of change of water level however, but the satellite data analyses mentioned above showed that emergent macrophytes were able to shift over a vertical gradient of 1.5m in 7 years (0.2m per year).</td><td>4</td></tr>
<tr><td>

☑ Area between 0.65 below and 0.3 above [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.112</td><td>-0.800</td><td></td></tr>
<tr><td></td><td>0.148</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>0.184</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.370</td><td>0.600</td><td></td></tr>
<tr><td>Max Base</td><td>0.556</td><td>0.800</td><td></td></tr>
<tr><td>Max</td><td>0.639</td><td>1.200</td><td></td></tr>
</table>

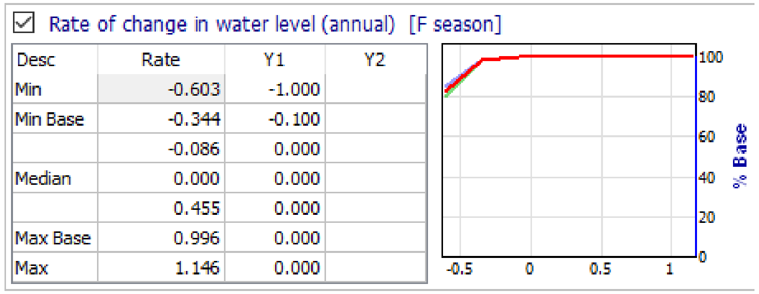
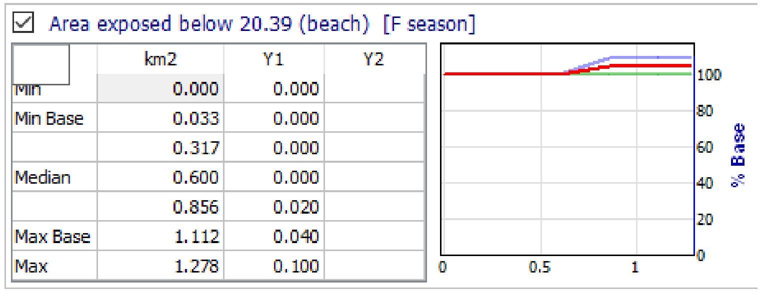
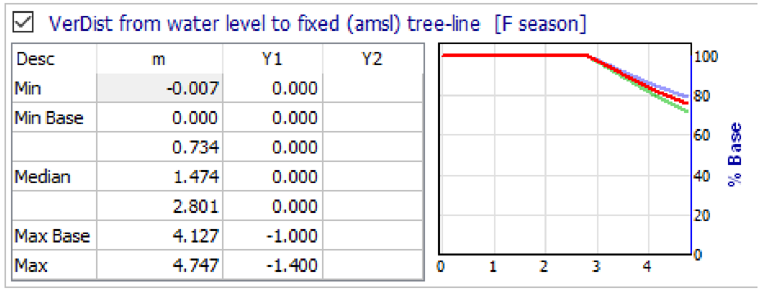
</td><td>Measurements in July 2015 found the optimal hydraulic habitat for emergent macrophytes as a group to be from 0.3m above water level (mortality of *Schoenoplectus scirpoides* was observed at 0.43m and 0.83m) to 0.65m below water level (*S. scirpoides* was found to a maximum depth of 2.28m). The relationship of emergent macrophyte abundance to habitable area is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>3</td></tr>
</table>

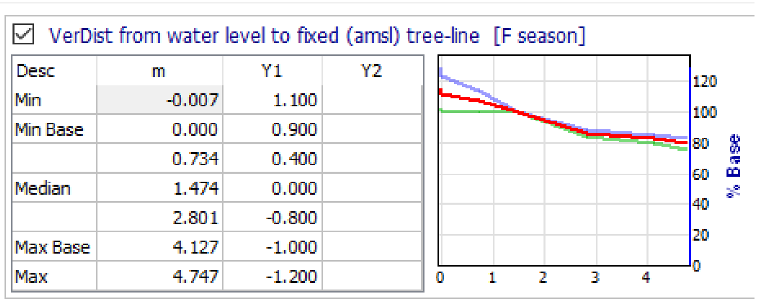
Emergent Macrophytes		
Response curve	Explanation	Confidence
	Emergent macrophytes are able to successfully grow to depths of 2.3m below water level (maximum recorded in July 2015) and frequently do so were such depths occur close to the water's edge (usually within 3-5m), but where shallow water occurs beyond these distances (such as at the extremities in the Western Arm), emergent macrophytes do not continue to colonise open water areas.	3

☑ Area 1.5 to 2 m deep [F season]

Desc	km2	Y1	Y2
Min	0.000	-2.600	
Min Base	0.074	-0.500	
	0.087	0.000	
Median	0.100	0.000	
	0.110	0.200	
Max Base	0.120	0.300	
Max	0.138	0.500	

<table>
<tr><th colspan="2">Shore “beach” Macrophytes</th><th></th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.200</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.200</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-0.200</td><td></td></tr>
</table>
</td><td>Rapid rates of increase are likely to cause some growth in the lower portions of the zone since most species representing this indicator are able to withstand and benefit from moderate inundation. Rapid rates of decline are likely to be detrimental to the zone with likely reductions in density. Rates of decline at or in excess of 0.5m per year will likely result in some desiccation stress, with associated reduction in density.</td><td>4</td></tr>
<tr><td>
☑ Area of beach between 0.6 and 3.8 above [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.723</td><td>-1.400</td><td></td></tr>
<tr><td></td><td>1.124</td><td>-0.700</td><td></td></tr>
<tr><td>Median</td><td>1.525</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.673</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>1.820</td><td>1.400</td><td></td></tr>
<tr><td>Max</td><td>2.093</td><td>2.600</td><td></td></tr>
</table>
</td><td>Measurements in July 2015 found the optimal hydraulic habitat for macrophytes on sandy "beach" areas as a group to be from 0.6m to 3.8m above water level (15.77mamsl). The relationship of "beach" macrophyte abundance to habitable area is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>3</td></tr>
</table>

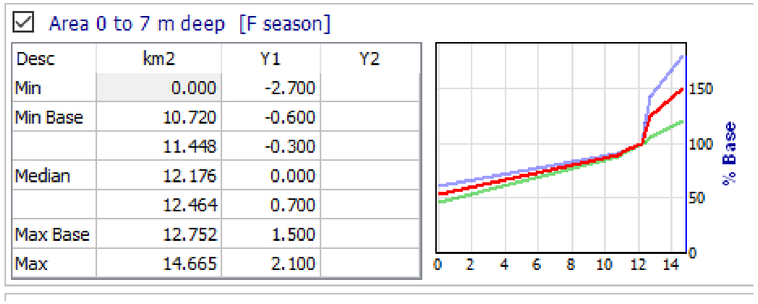
<table>
<tr><th colspan="2">Woody “lake-dependent” Vegetation</th><th></th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.100</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>0.000</td><td></td></tr>
</table>
</td><td>Cottonwood-willow forests (<i>Populus fremontii</i> and <i>Salix gooddingii</i>) were shown to be dense and multi-aged where intra-annual ground-water fluctuation was between about 0.5 and 1m (Lite and Stromberg 2005). Again, <i>S. cordatum</i> is a similar phreatophyte, so the relationship was applied to rates of decline greater than 0.5m/year, where tree density would likely decline.</td><td>4</td></tr>
<tr><td>
☑ Area exposed below 20.39 (beach) [F season]
<table>
<tr><th></th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.033</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.317</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.600</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.856</td><td>0.020</td><td></td></tr>
<tr><td>Max Base</td><td>1.112</td><td>0.040</td><td></td></tr>
<tr><td>Max</td><td>1.278</td><td>0.100</td><td></td></tr>
</table>
</td><td>The current tree line (indicated by <i>Syzygium cordatum</i>) is clearly defined by a distinct band of adult trees at about 20.4 mamsl. This clearly defined transition band is most likely maintained during periods of high lake levels which will cause mortality of trees colonising the beach area (from tree line to the water's edge). The records of lake level show that this occurs approximately every decade. During times of draw down when lake levels drop below about 20 mamsl the area of exposed beach will increase and become potential habitat for the colonisation of tree saplings, which will facilitate an expansion of the woody, lake-dependent vegetation, a phenomenon clearly observed to be in operation in July 2015.</td><td>4</td></tr>
<tr><td>
☑ VerDist from water level to fixed (amsl) tree-line [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.007</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.734</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>1.474</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.801</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>4.127</td><td>-1.000</td><td></td></tr>
<tr><td>Max</td><td>4.747</td><td>-1.400</td><td></td></tr>
</table>
</td><td>It is fair to assume that <i>Syzygium cordatum</i> is phreatophytic (due to its association with riparian zones, wetland fringes and other wetter areas) and therefore also drought-sensitive. Other, similar species such as <i>Populus fremontii</i> and <i>Salix gooddingii</i> have been shown to maintain dense, multi-aged stands where depth to ground water was less than 4m (Lite & Stromberg 2005). This general rule has been applied here to mark the point at which tree density and abundance is likely to decline due to desiccation stress.</td><td>4</td></tr>
</table>

Wetland & Pans associated with the Lake		
Response curve	Explanation	Confidence
	The wetlands and pans surrounding the lake occur at varying levels above the lake level and may or may not become connected to the lake at high water levels. Nevertheless it is assumed (as with the lake) that water levels in wetlands and pans are an expression of localised ground water levels, but will also be affected by rainfall. Just as the lake water level maintains the clearly defined tree line by way of periodic inundation (about once a decade) of the areas up to where adult trees currently occur (at an average of 20.4mamsl), the integrity of wetlands and pans will also be maintained by the same frequency and magnitude of inundation [at least]. Such inundation is important for the maintenance of non-woody species dominance and composition, and will keep wetlands and pans from becoming invaded by woody vegetation. Wetland and pan condition was therefore linked to vertical distance above lake level (relative to the tree line at 20.39mamsl) since this will likely reflect relative changes in ground water depth. A decreasing lake level is therefore taken to reflect an overall average increasing depth to ground water, which will result in differential drying of wetlands and pans. Such deterioration of wetland and pan condition will result in changes to vegetation composition and structure, with terrestrial species variously replacing wetland species.	3

☑ VerDist from water level to fixed (amsl) tree-line [F season]

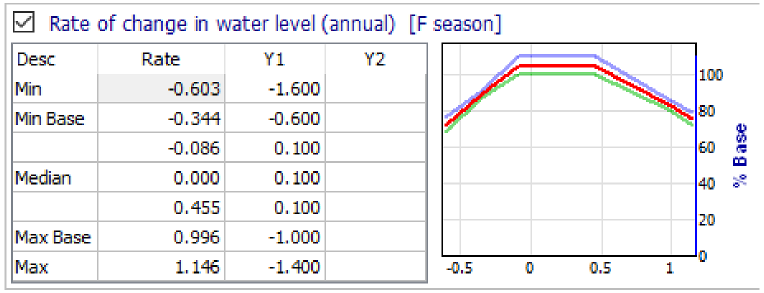
Desc	m	Y1	Y2
Min	-0.007	1.100	
Min Base	0.000	0.900	
	0.734	0.400	
Median	1.474	0.000	
	2.801	-0.800	
Max Base	4.127	-1.000	
Max	4.747	-1.200	

4.9.2 EWR Zone 2 – Main Basin

<table>
<tr><td colspan="2">Submerged aquatic macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Area 0 to 7 m deep [F season]

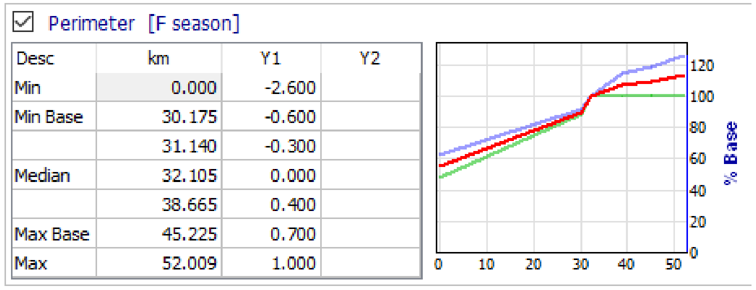
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.700</td><td></td></tr>
<tr><td>Min Base</td><td>10.720</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>11.448</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>12.176</td><td>0.000</td><td></td></tr>
<tr><td></td><td>12.464</td><td>0.700</td><td></td></tr>
<tr><td>Max Base</td><td>12.752</td><td>1.500</td><td></td></tr>
<tr><td>Max</td><td>14.665</td><td>2.100</td><td></td></tr>
</table>

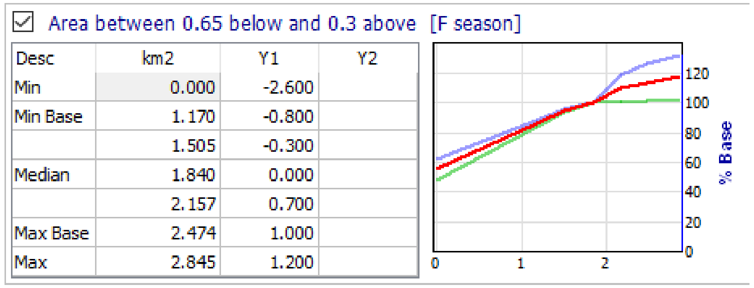
</td><td>Submerged macrophytes were less dense in the Main Basin due to exposure to wind and waves. Nevertheless depth relationships were similar, just with lower densities. Allanson (1979) found submerged macrophytes ringing the lake from depths of 1m to 7m and at this time the 1% level for white light was at 12m. Previously submerged macrophytes were found at depths of 9 to 12m (Boltt et al. 1969; Hill et al. 1975 in Bruton & Cooper 1980). When turbidity increased during high water levels however, submerged macrophytes were only found to depths of 5.5m and photosynthetically active radiation to 7 to 8m (Allanson 1979). During the field visit in July 2015 submerged macrophytes were found to occur from the water's edge to at least 2.5m, but it was not possible to sample greater depths. The relationship of submerged macrophytes to habitable area (0-7m depth, depending on turbidity) is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>4</td></tr>
<tr><td>

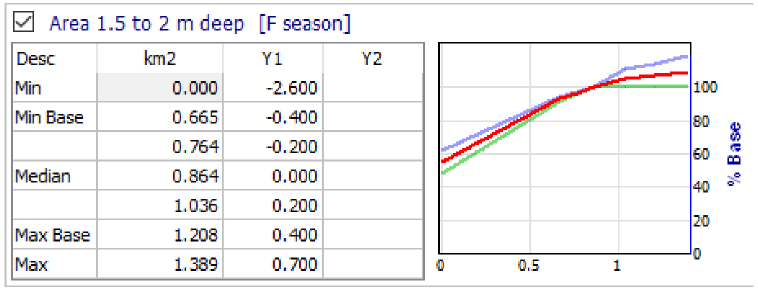
☑ Rate of change in water level (annual) [F season]

<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.600</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.100</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.100</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>-1.000</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-1.400</td><td></td></tr>
</table>

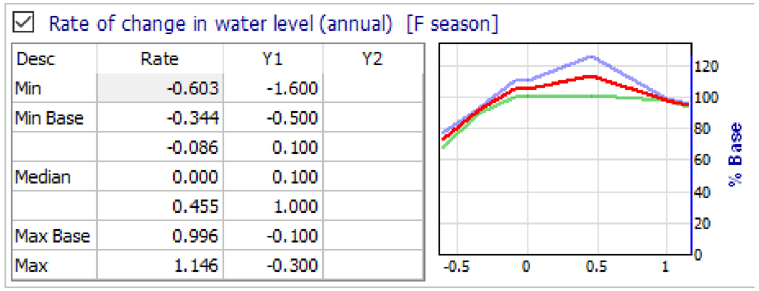
</td><td>It is likely that submerged macrophytes as a zone (0 to -7m water depth) will be able to shift relatively rapidly (within a growing season) if the rate of change in water level is slow. [Myriophyllum spicatum for example is able to achieve root growth tates of up to 1cm/day (Hussner et al. 2009)]. Conversely, the width of the zone is likely to shrink if rates of change are faster than the ability of plants to colonise newly available habitat. The critical rate of change of water level has been arbitrarily set at 0.5m per year. Rapid inundation to 0.5m is likely to result in a rapid increase in growth, but inundation beyond 1m is likely to reduce it. [Zhang et al. (2015) showed that the amplitude of water level fluctuation was the major determinant of M. spicatum biomass in various floodplain lakes].</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Emergent Macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Perimeter [F season]
<table>
<tr><th>Desc</th><th>km</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>30.175</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>31.140</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>32.105</td><td>0.000</td><td></td></tr>
<tr><td></td><td>38.665</td><td>0.400</td><td></td></tr>
<tr><td>Max Base</td><td>45.225</td><td>0.700</td><td></td></tr>
<tr><td>Max</td><td>52.009</td><td>1.000</td><td></td></tr>
</table>

</td><td>The wetted perimeter represents an area of potentially available habitat for emergent macrophytes which were found to be variously present from 40cm above water level to depths of 2.2m in July 2015. Furthermore, analyses of current and historic satellite data (Google Earth (C)) revealed that emergent macrophytes, as a zone, could shift as the water's edge did (from January 2006 through November 2010 to June 2013) i.e. small shifts in a little as 3 years. The ability of emergent macrophytes to shift in accordance with lake level will depend on the rates of change of water level however, but the satellite data analyses mentioned above showed that emergent macrophytes were able to shift over a vertical gradient of 1.5m in 7 years (0.2m per year).</td><td>4</td></tr>
<tr><td>

☑ Area between 0.65 below and 0.3 above [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>1.170</td><td>-0.800</td><td></td></tr>
<tr><td></td><td>1.505</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>1.840</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.157</td><td>0.700</td><td></td></tr>
<tr><td>Max Base</td><td>2.474</td><td>1.000</td><td></td></tr>
<tr><td>Max</td><td>2.845</td><td>1.200</td><td></td></tr>
</table>

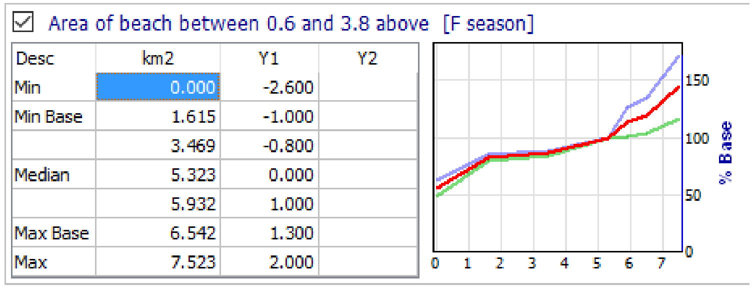
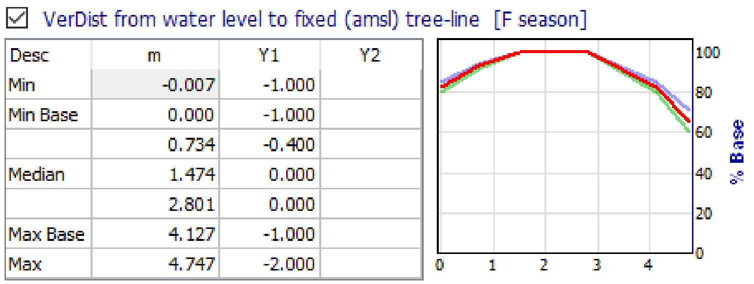
</td><td>Measurements in July 2015 found the optimal hydraulic habitat for emergent macrophytes as a group to be from 0.3m above water level (mortality of Schoenoplectus scirpoides was observed at 0.43m and 0.83m) to 0.65m below water level (S. scirpoides was found to a maximum depth of 2.28m). The relationship of emergent macrophyte abundance to habitable area is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>3</td></tr>
<tr><td>

☑ Area 1.5 to 2 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.665</td><td>-0.400</td><td></td></tr>
<tr><td></td><td>0.764</td><td>-0.200</td><td></td></tr>
<tr><td>Median</td><td>0.864</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.036</td><td>0.200</td><td></td></tr>
<tr><td>Max Base</td><td>1.208</td><td>0.400</td><td></td></tr>
<tr><td>Max</td><td>1.389</td><td>0.700</td><td></td></tr>
</table>

</td><td>Emergent macrophytes are able to successfully grow to depths of 2.3m below water level (maximum recorded in July 2015) and frequently do so were such depths occur close to the water's edge (usually within 3-5m), but where shallow water occurs beyond these distances (such as at the extremities in the Western Arm), emergent macrophytes do not continue to colonise open water areas.</td><td>3</td></tr>
</table>

Emergent Macrophytes		
Response curve	Explanation	Confidence
	Water level fluctuations were superimposed on satellite data (Google Earth) and related to emergent macrophyte zone integity. Data showed that in exposed areas a rate of water level decline of 0.2m/year [or more] was associated with emergent macrophytes that were not able to track the declining shift in water level. In sheltered areas however, emergent macrophytes were able to shift with declining water level, up to a rate of 0.36m/year. Sample size was limited however which severely retards a better understanding of the exact relationship. The Western Arm was treated as having an abundance of sheltered sites. Rapid inundation to 0.5m is likely to result in a rapid increase in growth, but inundation beyond 1m is likely to reduce it.	3

☑ Rate of change in water level (annual) [F season]

Desc	Rate	Y1	Y2
Min	-0.603	-1.600	
Min Base	-0.344	-0.500	
	-0.086	0.100	
Median	0.000	0.100	
	0.455	1.000	
Max Base	0.996	-0.100	
Max	1.146	-0.300	

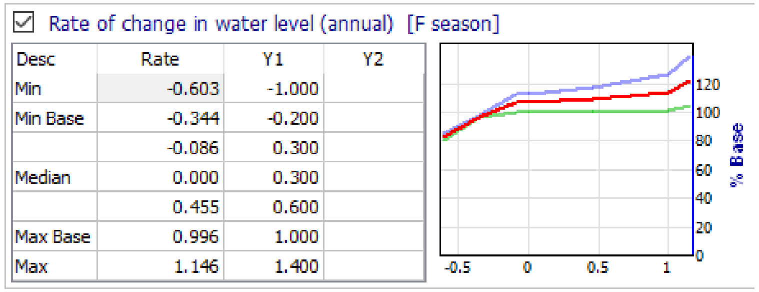
Shore "beach" Macrophytes		
Response curve	Explanation	Confidence
	Measurements in July 2015 found the optimal hydraulic habitat for macrophytes on sandy "beach" areas as a group to be from 0.6m to 3.8m above water level (15.77 mamsl). The relationship of "beach" macrophyte abundance to habitable area is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.	3
	It is likely that once vertical distance to ground water reaches and exceeds 4m that density and abundance will sharply decline with water stress-related mortality	3

☑ Area of beach between 0.6 and 3.8 above [F season]

Desc	km2	Y1	Y2
Min	0.000	-2.600	
Min Base	1.615	-1.000	
	3.469	-0.800	
Median	5.323	0.000	
	5.932	1.000	
Max Base	6.542	1.300	
Max	7.523	2.000	

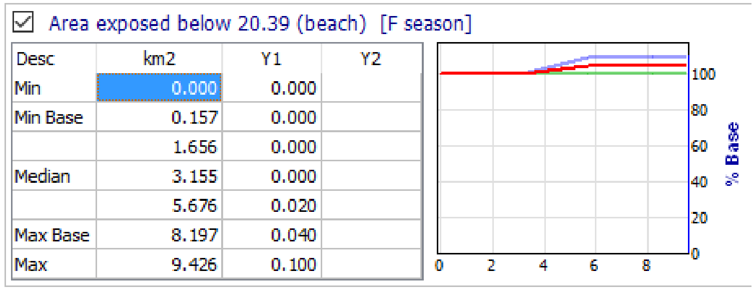
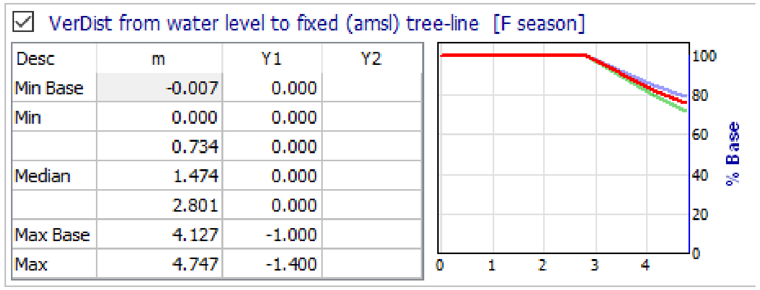
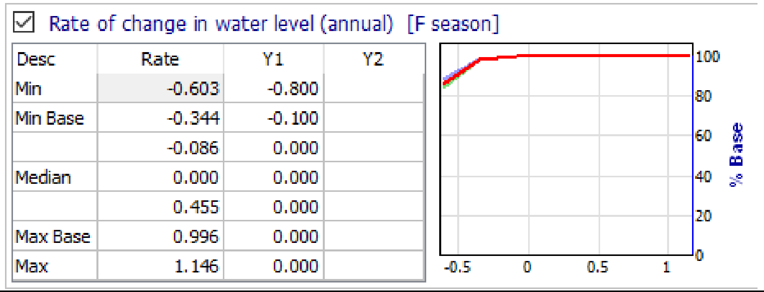
☑ VerDist from water level to fixed (amsl) tree-line [F season]

Desc	m	Y1	Y2
Min	-0.007	-1.000	
Min Base	0.000	-1.000	
	0.734	-0.400	
Median	1.474	0.000	
	2.801	0.000	
Max Base	4.127	-1.000	
Max	4.747	-2.000	

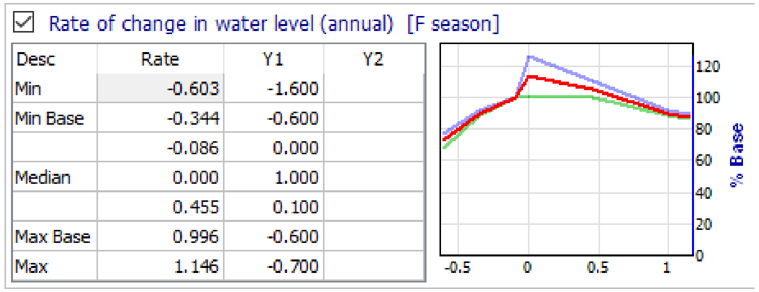
Shore "beach" Macrophytes		
Response curve	Explanation	Confidence
	Rapid rates of increase are likely to cause some growth in the lower portions of the zone since most species representing this indicator are able to withstand and benefit from moderate inundation. Rapid rates of decline are likely to be detrimental to the zone with likely reductions in density. Rates of decline at or in excess of 0.5m per year will likely result in some desiccation stress, with associated reduction in density.	3

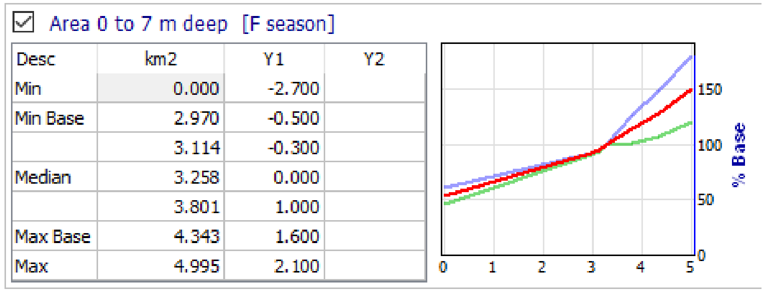
☑ Rate of change in water level (annual) [F season]

Desc	Rate	Y1	Y2
Min	-0.603	-1.000	
Min Base	-0.344	-0.200	
	-0.086	0.300	
Median	0.000	0.300	
	0.455	0.600	
Max Base	0.996	1.000	
Max	1.146	1.400	

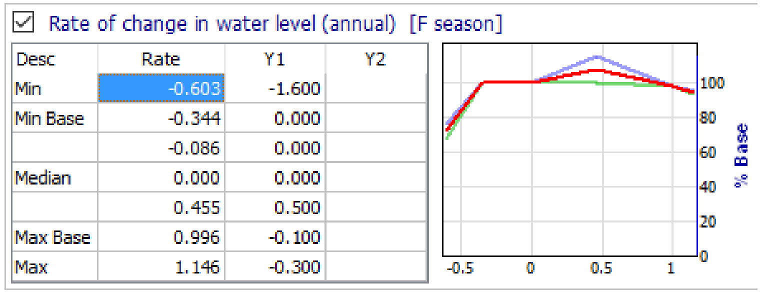
<table>
<tr><td colspan="2">Woody “lake-dependent” Vegetation</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area exposed below 20.39 (beach) [F season]
<table>
<tr><td>Desc</td><td>km2</td><td>Y1</td><td>Y2</td></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.157</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.656</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>3.155</td><td>0.000</td><td></td></tr>
<tr><td></td><td>5.676</td><td>0.020</td><td></td></tr>
<tr><td>Max Base</td><td>8.197</td><td>0.040</td><td></td></tr>
<tr><td>Max</td><td>9.426</td><td>0.100</td><td></td></tr>
</table>
</td><td>The current tree line (indicated by Syzygium cordatum) is clearly defined by a distinct band of adult trees at about 20.4 mamsl. This clearly defined transition band is most likely maintained during periods of high lake levels which will cause mortality of trees colonising the beach area (from tree line to the water's edge). The records of lake level show that this occurs approximately every decade. During times of draw down when lake levels drop below about 20 mamsl the area of exposed beach will increase and become potential habitat for the colonisation of tree saplings, which will facilitate an expansion of the woody, lake-dependent vegetation, a phenomenon clearly observed to be in operation in July 2015.</td><td>3</td></tr>
<tr><td>
☑ VerDist from water level to fixed (amsl) tree-line [F season]
<table>
<tr><td>Desc</td><td>m</td><td>Y1</td><td>Y2</td></tr>
<tr><td>Min Base</td><td>-0.007</td><td>0.000</td><td></td></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.734</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>1.474</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.801</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>4.127</td><td>-1.000</td><td></td></tr>
<tr><td>Max</td><td>4.747</td><td>-1.400</td><td></td></tr>
</table>
</td><td>It is fair to assume that Syzygium cordatum is phreatophytic (due to its association with riparian zones, wetland fringes and other wetter areas) and therefore also drought-sensitive. Other, similar species such as Populus fremontii and Salix gooddingii have been shown to maintain dense, multi-aged stands where depth to ground water was less than 4m (Lite & Stromberg 2005). This general rule has been applied here to mark the point at which tree density and abundance is likely to decline due to desiccation stress.</td><td>4</td></tr>
<tr><td>
☑ Rate of change in water level (annual) [F season]
<table>
<tr><td>Desc</td><td>Rate</td><td>Y1</td><td>Y2</td></tr>
<tr><td>Min</td><td>-0.603</td><td>-0.800</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.100</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>0.000</td><td></td></tr>
</table>
</td><td>Cottonwood-willow forests (Populus fremontii and Salix gooddingii) were shown to be dense and multi-aged where intra-annual ground-water fluctuation was between about 0.5 and 1m (Lite and Stromberg 2005). Again, S. cordatum is a similar phreatophyte, so the relationship was applied to rates of decline greater than 0.5m/year, where tree density would likely decline.</td><td>3</td></tr>
</table>

4.9.3 EWR Zone 3 – Northern Arm

<table>
<tr><td colspan="2">Submerged aquatic macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.600</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>1.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>-0.600</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-0.700</td><td></td></tr>
</table>

</td><td>It is likely that submerged macrophytes as a zone (0 to -7m water depth) will be able to shift relatively rapidly (within a growing season) if the rate of change in water level is slow. [Myriophyllum spicatum for example is able to achieve root growth rates of up to 1cm/day (Hussner *et al*. 2009)]. Conversely, the width of the zone is likely to shrink if rates of change are faster than the ability of plants to colonise newly available habitat. The critical rate of change of water level has been arbitrarily set at 0.5m per year. Rapid inundation to 0.5m is likely to result in a rapid increase in growth, but inundation beyond 1m is likely to reduce it. [Zhang *et al*. (2015) showed that the amplitude of water level fluctuation was the major determinant of M. spicatum biomass in various floodplain lakes].</td><td>4</td></tr>
<tr><td>

☑ Area 0 to 7 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.700</td><td></td></tr>
<tr><td>Min Base</td><td>2.970</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>3.114</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>3.258</td><td>0.000</td><td></td></tr>
<tr><td></td><td>3.801</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>4.343</td><td>1.600</td><td></td></tr>
<tr><td>Max</td><td>4.995</td><td>2.100</td><td></td></tr>
</table>

</td><td>Allanson (1979) found submerged macrophytes ringing the lake from depths of 1m to 7m and at this time the 1% level for white light was at 12m. Previously submerged macrophytes were found at depths of 9 to 12m (Boltt *et al*. 1969; Hill *et al*. 1975 in Bruton & Cooper 1980). When turbidity increased during high water levels however, submerged macrophytes were only found to depths of 5.5m and photosynthetically active radiation to 7 to 8m (Allanson 1979). During the field visit in July 2015 submerged macrophytes were found to occur from the water's edge to at least 2.5m, but it was not possible to sample greater depths. The relationship of submerged macrophytes to habitable area (0-7m depth, depending on turbidity) is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>4</td></tr>
</table>

<table>
<tr><th colspan="2">Emergent Macrophytes</th><th></th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.600</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>0.000</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
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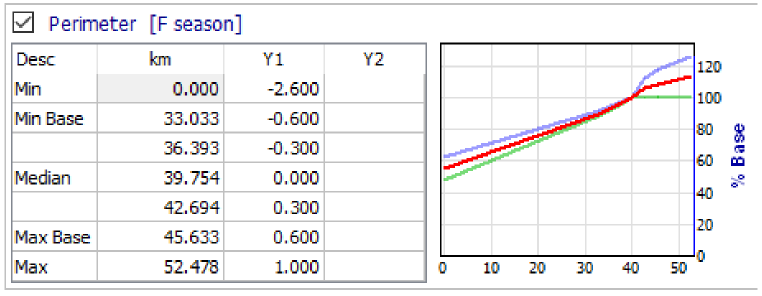
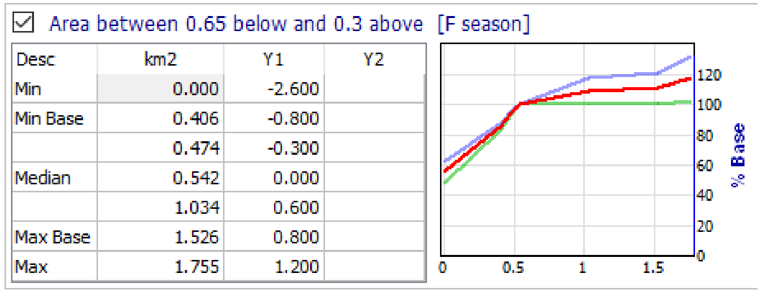
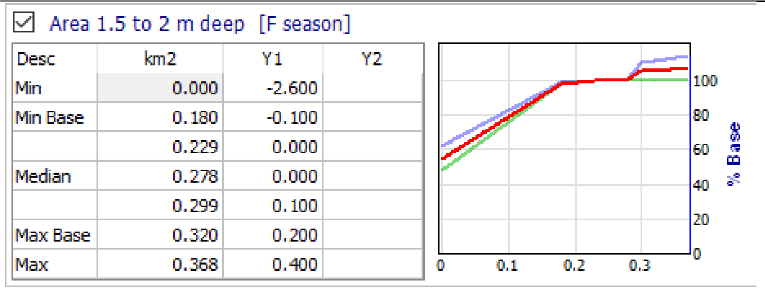
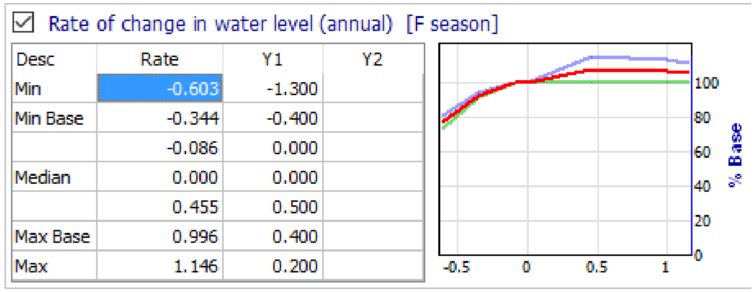
<tr><td>Max Base</td><td>0.996</td><td>-0.100</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-0.300</td><td></td></tr>
</table>
</td><td>Water level fluctuations were superimposed on satellite data (Google Earth) and related to emergent macrophyte zone integrity. Data showed that in exposed areas a rate of water level decline of 0.2m/year [or more] was associated with emergent macrophytes that were not able to track the declining shift in water level. In sheltered areas however, emergent macrophytes were able to shift with declining water level, up to a rate of 0.36m/year. Sample size was limited however which severely retards a better understanding of the exact relationship. The Northern Arm was treated as having an abundance of sheltered sites. Rapid inundation to 0.5m is likely to result in a rapid increase in growth, but inundation beyond 1m is likely to reduce it.</td><td>4</td></tr>
<tr><td>
☑ Perimeter [F season]
<table>
<tr><th>Desc</th><th>km</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>33.033</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>36.393</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>39.754</td><td>0.000</td><td></td></tr>
<tr><td></td><td>42.694</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>45.633</td><td>0.600</td><td></td></tr>
<tr><td>Max</td><td>52.478</td><td>1.000</td><td></td></tr>
</table>
</td><td>The wetted perimeter represents an area of potentially available habitat for emergent macrophytes which were found to be variously present from 40cm above water level to depths of 2.2m in July 2015. Furthermore, analyses of current and historic satellite data (Google Earth (C)) revealed that emergent macrophytes, as a zone, could shift as the water's edge did (from January 2006 through November 2010 to June 2013) i.e. small shifts in a little as 3 years. The ability of emergent macrophytes to shift in accordance with lake level will depend on the rates of change of water level however, but the satellite data analyses mentioned above showed that emergent macrophytes were able to shift over a vertical gradient of 1.5m in 7 years (0.2m per year).</td><td>4</td></tr>
<tr><td>
☑ Area between 0.65 below and 0.3 above [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.406</td><td>-0.800</td><td></td></tr>
<tr><td></td><td>0.474</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>0.542</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.034</td><td>0.600</td><td></td></tr>
<tr><td>Max Base</td><td>1.526</td><td>0.800</td><td></td></tr>
<tr><td>Max</td><td>1.755</td><td>1.200</td><td></td></tr>
</table>
</td><td>Measurements in July 2015 found the optimal hydraulic habitat for emergent macrophytes as a group to be from 0.3m above water level (mortality of Schoenoplectus scirpoides was observed at 0.43m and 0.83m) to 0.65m below water level (S. scirpoides was found to a maximum depth of 2.28m). The relationship of emergent macrophyte abundance to habitable area is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Emergent Macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


☑ Area 1.5 to 2 m deep [F season]

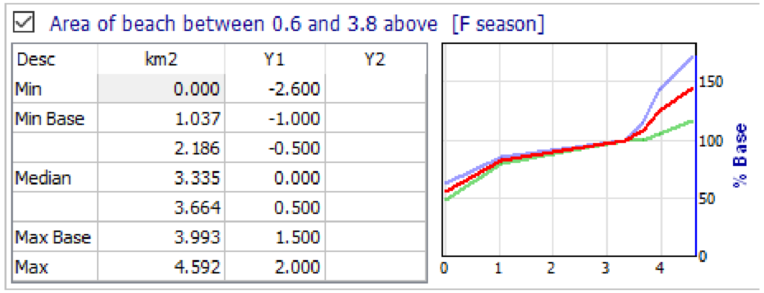
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.180</td><td>-0.100</td><td></td></tr>
<tr><td></td><td>0.229</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.278</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.299</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>0.320</td><td>0.200</td><td></td></tr>
<tr><td>Max</td><td>0.368</td><td>0.400</td><td></td></tr>
</table>

</td><td>Emergent macrophytes are able to successfully grow to depths of 2.3m below water level (maximum recorded in July 2015) and frequently do so were such depths occur close to the water's edge (usually within 3-5m), but where shallow water occurs beyond these distances (such as at the extremities in the Northern Arm), emergent macrophytes do not continue to colonise open water areas.</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Shore “beach” Macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


☑ Rate of change in water level (annual) [F season]

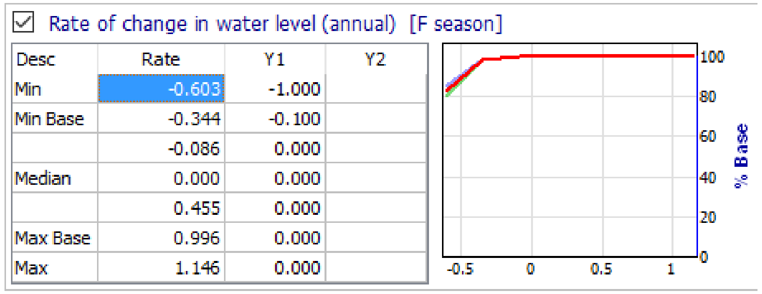
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.300</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.400</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>0.400</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>0.200</td><td></td></tr>
</table>

</td><td>Rapid rates of increase are likely to cause some growth in the lower portions of the zone since most species representing this indicator are able to withstand and benefit from moderate inundation. Rapid rates of decline are likely to be detrimental to the zone with likely reductions in density. Rates of decline at or in excess of 0.5m per year will likely result in some desiccation stress, with associated reduction in density.</td><td>3</td></tr>
<tr><td>


☑ Area of beach between 0.6 and 3.8 above [F season]

<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>1.037</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>2.186</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>3.335</td><td>0.000</td><td></td></tr>
<tr><td></td><td>3.664</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>3.993</td><td>1.500</td><td></td></tr>
<tr><td>Max</td><td>4.592</td><td>2.000</td><td></td></tr>
</table>

</td><td>Measurements in July 2015 found the optimal hydraulic habitat for macrophytes on sandy "beach" areas as a group to be from 0.6m to 3.8m above water level (15.77 mamsl). The relationship of "beach" macrophyte abundance to habitable area is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Woody “lake-dependent” Vegetation</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.100</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
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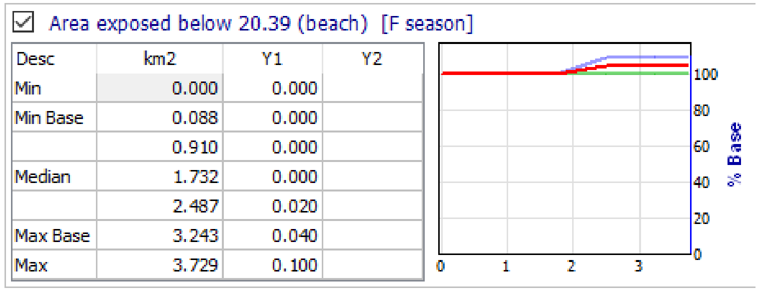
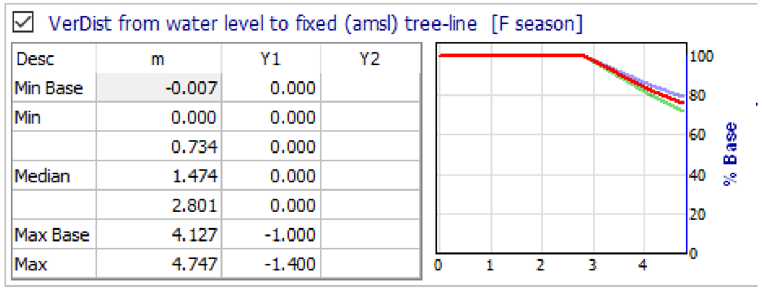
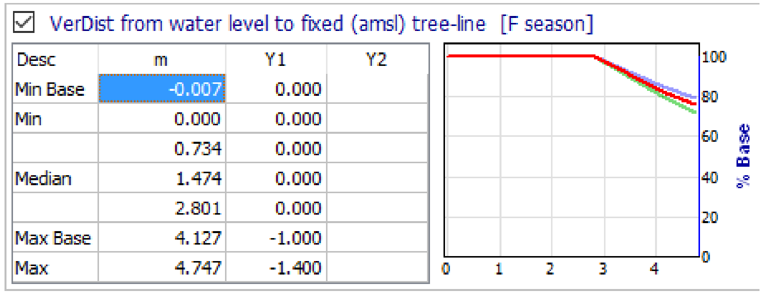
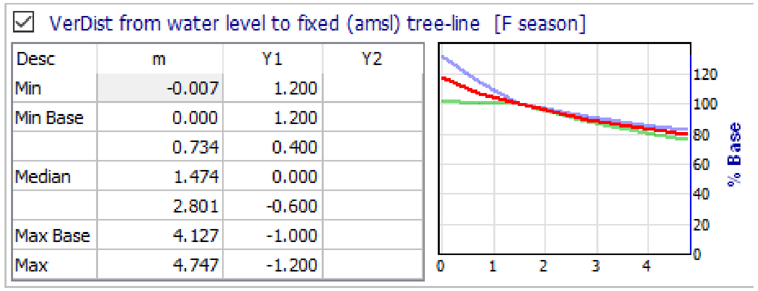
<tr><td>Max Base</td><td>0.996</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>0.000</td><td></td></tr>
</table>
</td><td>Cottonwood-willow forests (Populus fremontii and Salix gooddingii) were shown to be dense and multi-aged where intra-annual ground-water fluctuation was between about 0.5 and 1m (Lite and Stromberg 2005). Again, S. cordatum is a similar phreatophyte, so the relationship was applied to rates of decline greater than 0.5m/year, where tree density would likely decline.</td><td>4</td></tr>
<tr><td>
☑ Area exposed below 20.39 (beach) [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.088</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.910</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>1.732</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.487</td><td>0.020</td><td></td></tr>
<tr><td>Max Base</td><td>3.243</td><td>0.040</td><td></td></tr>
<tr><td>Max</td><td>3.729</td><td>0.100</td><td></td></tr>
</table>
</td><td>The current tree line (indicated by Syzygium cordatum) is clearly defined by a distinct band of adult trees at about 20.4 mamsl. This clearly defined transition band is most likely maintained during periods of high lake levels which will cause mortality of trees colonising the beach area (from tree line to the water's edge). The records of lake level show that this occurs approximately every decade. During times of draw down when lake levels drop below about 20 mamsl the area of exposed beach will increase and become potential habitat for the colonisation of tree saplings, which will facilitate an expansion of the woody, lake-dependent vegetation, a phenomenon clearly observed to be in operation in July 2015.</td><td>3</td></tr>
<tr><td>
☑ VerDist from water level to fixed (amsl) tree-line [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min Base</td><td>-0.007</td><td>0.000</td><td></td></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.734</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>1.474</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.801</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>4.127</td><td>-1.000</td><td></td></tr>
<tr><td>Max</td><td>4.747</td><td>-1.400</td><td></td></tr>
</table>
</td><td>It is fair to assume that Syzygium cordatum is phreatophytic (due to its association with riparian zones, wetland fringes and other wetter areas) and therefore also drought-sensitive. Other, similar species such as Populus fremontii and Salix gooddingii have been shown to maintain dense, multi-aged stands where depth to ground water was less than 4m (Lite & Stromberg 2005). This general rule has been applied here to mark the point at which tree density and abundance is likely to decline due to desiccation stress.</td><td>3</td></tr>
</table>

Swamp Forest		
Response curve	Explanation	Confidence
	There were no elevation data available for swamp forest, but it is assumed here that Ficus trichopoda has comparable ability to utilise ground water than S. cordatum where it occurs. The same rule was thus applied as for S. cordatum in terms of distance to ground water (repeated here for clarity): It is fair to assume that Syzygium cordatum is phreatophytic (due to its association with riparian zones, wetland fringes and other wetter areas) and therefore also drought-sensitive. Other, similar species such as Populus fremontii and Salix gooddingii have been shown to maintain dense, multi-aged stands where depth to ground water was less than 4m (Lite & Stromberg 2005). This general rule has been applied here to mark the point at which tree density and abundance is likely to decline due to desiccation stress.	3

☑ VerDist from water level to fixed (amsl) tree-line [F season]

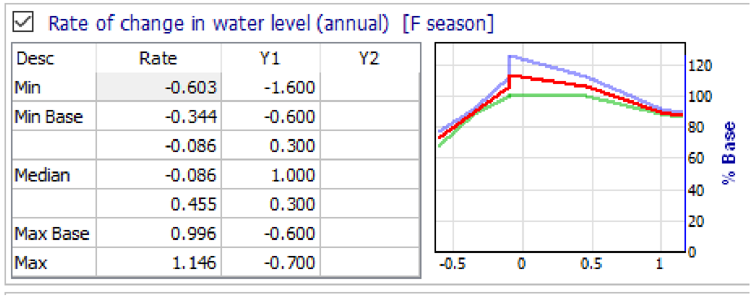
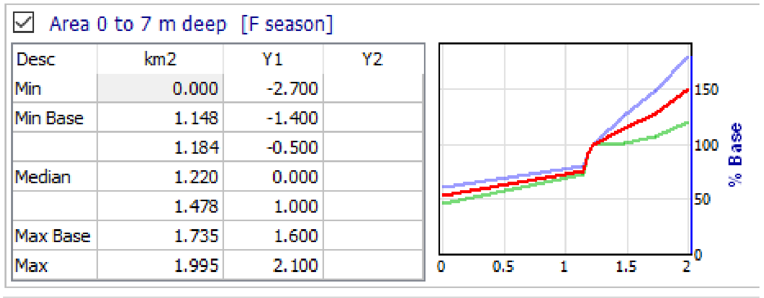
Desc	m	Y1	Y2
Min Base	-0.007	0.000	
Min	0.000	0.000	
	0.734	0.000	
Median	1.474	0.000	
	2.801	0.000	
Max Base	4.127	-1.000	
Max	4.747	-1.400	

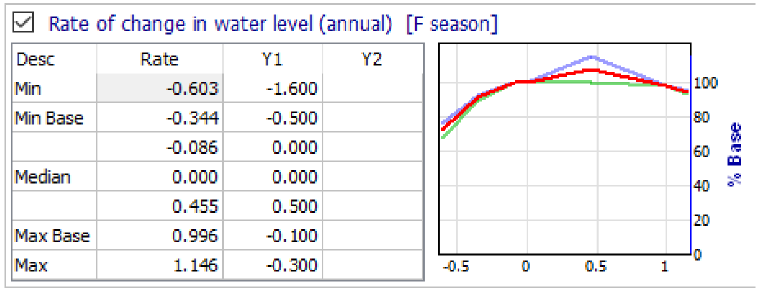
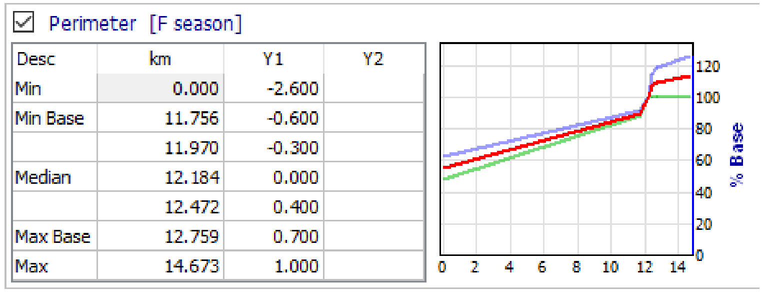
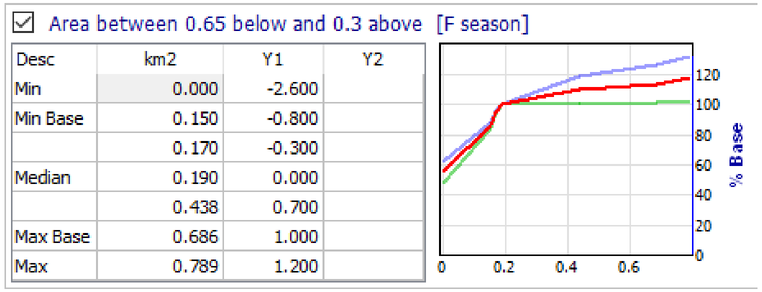
Wetlands & Pans associated with the lake		
Response curve	Explanation	Confidence
	The wetlands and pans surrounding the lake occur at varying levels above the lake level and may or may not become connected to the lake at high water levels. Nevertheless it is assumed (as with the lake) that water levels in wetlands and pans are an expression of localised ground water levels, but will also be affected by rainfall. Just as the lake water level maintains the clearly defined tree line by way of periodic inundation (about once a decade) of the areas up to where adult trees currently occur (at an average of 20.4 mamsl), the integrity of wetlands and pans will also be maintained by the same frequency and magnitude of inundation [at least]. Such inundation is important for the maintenance of non-woody species dominance and composition, and will keep wetlands and pans from becoming invaded by woody vegetation. Wetland and pan condition was therefore linked to vertical distance above lake level (relative to the tree line at 20.39 mamsl) since this will likely reflect relative changes in ground water depth. A decreasing lake level is therefore taken to reflect an overall average increasing depth to ground water, which will result in differential drying of wetlands and pans. Such deterioration of wetland and pan condition will result in changes to vegetation composition and structure, with terrestrial species variously replacing wetland species.	3

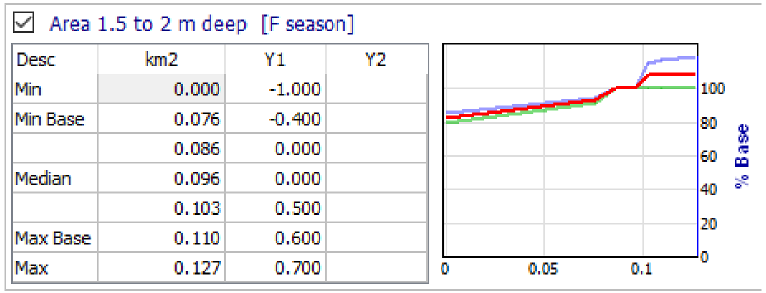
☑ VerDist from water level to fixed (amsl) tree-line [F season]

Desc	m	Y1	Y2
Min	-0.007	1.200	
Min Base	0.000	1.200	
	0.734	0.400	
Median	1.474	0.000	
	2.801	-0.600	
Max Base	4.127	-1.000	
Max	4.747	-1.200	

4.9.4 EWR Zone 4 – Southwestern Basin

<table>
<tr><td colspan="2">Submerged aquatic macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.600</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.300</td><td></td></tr>
<tr><td>Median</td><td>-0.086</td><td>1.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>-0.600</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-0.700</td><td></td></tr>
</table>
</td><td>It is likely that submerged macrophytes as a zone (0 to -7m water depth) will be able to shift relatively rapidly (within a growing season) if the rate of change in water level is slow. [Myriophyllum spicatum for example is able to achieve root growth tates of up to 1cm/day (Hussner <i>et al</i>. 2009)]. Conversely, the width of the zone is likely to shrink if rates of change are faster than the ability of plants to colonise newly available habitat. The critical rate of change of water level has been arbitrarily set at 0.5m per year. Rapid inundation to 0.5m is likely to result in a rapid increase in growth, but inundation beyond 1m is likely to reduce it. [Zhang <i>et al</i>. (2015) showed that the amplitude of water level fluctuation was the major determinant of M. spicatum biomass in various floodplain lakes].</td><td>4</td></tr>
<tr><td>
☑ Area 0 to 7 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.700</td><td></td></tr>
<tr><td>Min Base</td><td>1.148</td><td>-1.400</td><td></td></tr>
<tr><td></td><td>1.184</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>1.220</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.478</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>1.735</td><td>1.600</td><td></td></tr>
<tr><td>Max</td><td>1.995</td><td>2.100</td><td></td></tr>
</table>
</td><td>Allanson (1979) found submerged macrophytes fringing the lake from depths of 1m to 7m and at this time the 1% level for white light was at 12m. Previously submerged macrophytes were found at depths of 9 to 12m (Boltt <i>et al</i>. 1969; Hill <i>et al</i>. 1975 in Bruton & Cooper 1980). When turbidity increased during high water levels however, submerged macrophytes were only found to depths of 5.5m and photosynthetically active radiation to 7 to 8m (Allanson 1979). During the field visit in July 2015 submerged macrophytes were found to occur from the water's edge to at least 2.5m, but it was not possible to sample greater depths. The relationship of submerged macrophytes to habitable area (0-7m depth, depending on turbidity) is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>4</td></tr>
</table>

<table>
<tr><th colspan="2">Emergent macrophytes</th><th></th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.600</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>-0.100</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-0.300</td><td></td></tr>
</table>
</td>
<td>Water level fluctuations were superimposed on satellite data (Google Earth) and related to emergent macrophyte zone integrity. Data showed that in exposed areas a rate of water level decline of 0.2m/year [or more] was associated with emergent macrophytes that were not able to track the declining shift in water level. In sheltered areas however, emergent macrophytes were able to shift with declining water level, up to a rate of 0.36m/year. Sample size was limited however which severely retards a better understanding of the exact relationship. The Western Arm was treated as having an abundance of sheltered sites. Rapid inundation to 0.5m is likely to result in a rapid increase in growth, but inundation beyond 1m is likely to reduce it.</td>
<td>3</td></tr>
<tr><td>
☑ Perimeter [F season]
<table>
<tr><th>Desc</th><th>km</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>11.756</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>11.970</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>12.184</td><td>0.000</td><td></td></tr>
<tr><td></td><td>12.472</td><td>0.400</td><td></td></tr>
<tr><td>Max Base</td><td>12.759</td><td>0.700</td><td></td></tr>
<tr><td>Max</td><td>14.673</td><td>1.000</td><td></td></tr>
</table>
</td>
<td>The wetted perimeter represents an area of potentially available habitat for emergent macrophytes which were found to be variously present from 40cm above water level to depths of 2.2m in July 2015. Furthermore, analyses of current and historic satellite data (Google Earth (C)) revealed that emergent macrophytes, as a zone, could shift as the water's edge did (from January 2006 through November 2010 to June 2013) i.e. small shifts in a little as 3 years. The ability of emergent macrophytes to shift in accordance with lake level will depend on the rates of change of water level however, but the satellite data analyses mentioned above showed that emergent macrophytes were able to shift over a vertical gradient of 1.5m in 7 years (0.2m per year).</td>
<td>4</td></tr>
<tr><td>
☑ Area between 0.65 below and 0.3 above [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.150</td><td>-0.800</td><td></td></tr>
<tr><td></td><td>0.170</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>0.190</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.438</td><td>0.700</td><td></td></tr>
<tr><td>Max Base</td><td>0.686</td><td>1.000</td><td></td></tr>
<tr><td>Max</td><td>0.789</td><td>1.200</td><td></td></tr>
</table>
</td>
<td>Measurements in July 2015 found the optimal hydraulic habitat for emergent macrophytes as a group to be from 0.3m above water level (mortality of Schoenoplectus scirpoides was observed at 0.43m and 0.83m) to 0.65m below water level (S. scirpoides was found to a maximum depth of 2.28m). The relationship of emergent macrophyte abundance to habitable area is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td>
<td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Emergent macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area 1.5 to 2 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.076</td><td>-0.400</td><td></td></tr>
<tr><td></td><td>0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.096</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.103</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>0.110</td><td>0.600</td><td></td></tr>
<tr><td>Max</td><td>0.127</td><td>0.700</td><td></td></tr>
</table>
</td><td>Emergent macrophytes are able to successfully grow to depths of 2.3m below water level (maximum recorded in July 2015) and frequently do so were such depths occur close to the water's edge (usually within 3-5m), but where shallow water occurs beyond these distances (such as at the extremities in the Western Arm), emergent macrophytes do not continue to colonise open water areas.</td><td>3</td></tr>
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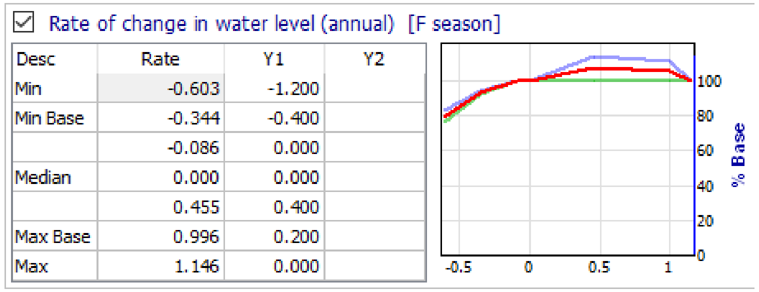
<tr><td>
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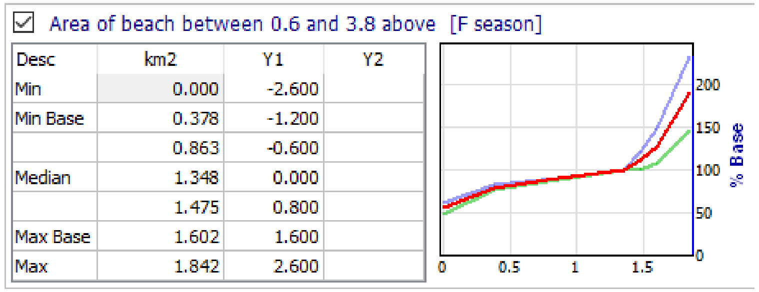
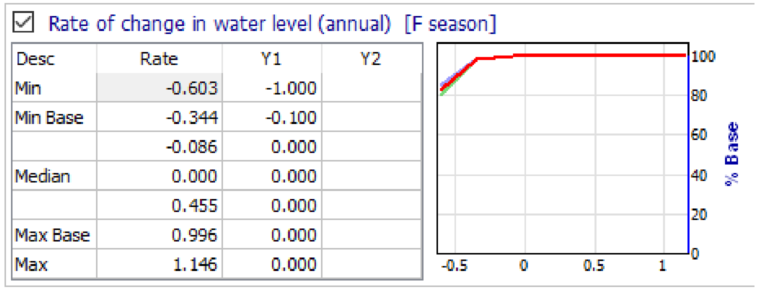
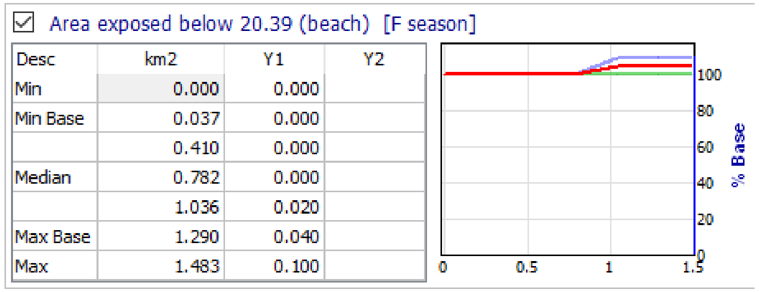
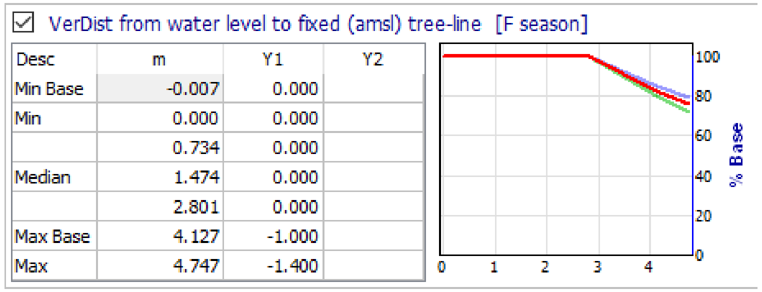
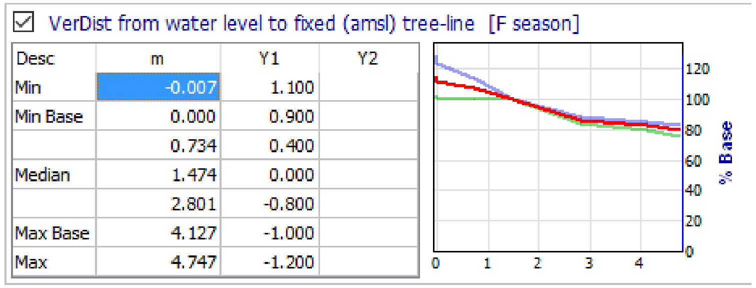
</td><td>Rapid rates of increase are likely to cause some growth in the lower portions of the zone since most species representing this indicator are able to withstand and benefit from moderate inundation. Rapid rates of decline are likely to be detrimental to the zone with likely reductions in density. Rates of decline at or in excess of 0.5m per year will likely result in some desiccation stress, with associated reduction in density.</td><td>3</td></tr>
<tr><td>
☑ Area of beach between 0.6 and 3.8 above [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.378</td><td>-1.200</td><td></td></tr>
<tr><td></td><td>0.863</td><td>-0.600</td><td></td></tr>
<tr><td>Median</td><td>1.348</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.475</td><td>0.800</td><td></td></tr>
<tr><td>Max Base</td><td>1.602</td><td>1.600</td><td></td></tr>
<tr><td>Max</td><td>1.842</td><td>2.600</td><td></td></tr>
</table>
</td><td>Measurements in July 2015 found the optimal hydraulic habitat for macrophytes on sandy "beach" areas as a group to be from 0.6m to 3.8m above water level (15.77 mamsl). The relationship of "beach" macrophyte abundance to habitable area is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>3</td></tr>
</table>

<table>
<tr><th colspan="2">Woody “lake-dependent” vegetation</th><th></th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>

☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.100</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>0.000</td><td></td></tr>
</table>

</td><td>Cottonwood-willow forests (Populus fremontii and Salix gooddingii) were shown to be dense and multi-aged where intra-annual ground-water fluctuation was between about 0.5 and 1m (Lite and Stromberg 2005). Again, S. cordatum is a similar phreatophyte, so the relationship was applied to rates of decline greater than 0.5m/year, where tree density would likely decline.</td><td>4</td></tr>
<tr><td>

☑ Area exposed below 20.39 (beach) [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.037</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.410</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.782</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.036</td><td>0.020</td><td></td></tr>
<tr><td>Max Base</td><td>1.290</td><td>0.040</td><td></td></tr>
<tr><td>Max</td><td>1.483</td><td>0.100</td><td></td></tr>
</table>

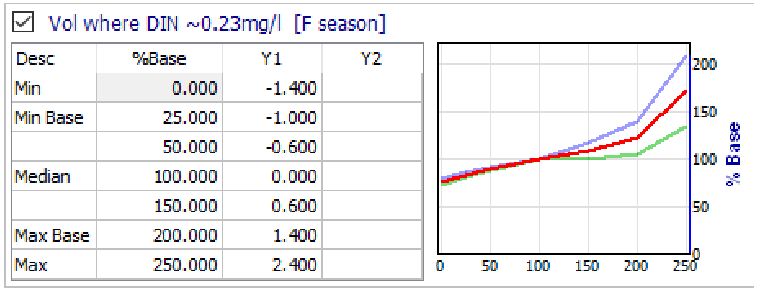
</td><td>The current tree line (indicated by Syzygium cordatum) is clearly defined by a distinct band of adult trees at about 20.4 mamsl. This clearly defined transition band is most likely maintained during periods of high lake levels which will cause mortality of trees colonising the beach area (from tree line to the water's edge). The records of lake level show that this occurs approximately every decade. During times of draw down when lake levels drop below about 20 mamsl the area of exposed beach will increase and become potential habitat for the colonisation of tree saplings, which will facilitate an expansion of the woody, lake-dependent vegetation, a phenomenon clearly observed to be in operation in July 2015.</td><td>3</td></tr>
<tr><td>

☑ VerDist from water level to fixed (amsl) tree-line [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min Base</td><td>-0.007</td><td>0.000</td><td></td></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.734</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>1.474</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.801</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>4.127</td><td>-1.000</td><td></td></tr>
<tr><td>Max</td><td>4.747</td><td>-1.400</td><td></td></tr>
</table>

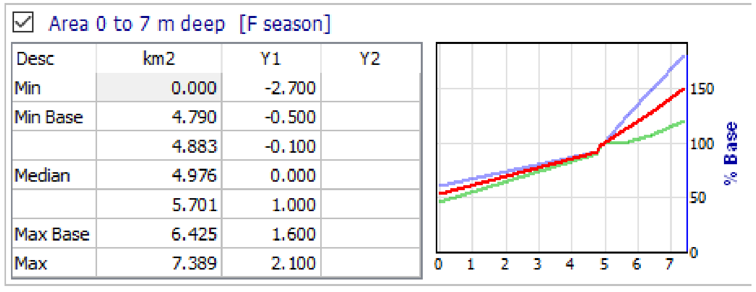
</td><td>It is fair to assume that Syzygium cordatum is phreatophytic (due to its association with riparian zones, wetland fringes and other wetter areas) and therefore also drought-sensitive. Other, similar species such as Populus fremontii and Salix gooddingii have been shown to maintain dense, multi-aged stands where depth to ground water was less than 4m (Lite & Stromberg 2005). This general rule has been applied here to mark the point at which tree density and abundance is likely to decline due to desiccation stress.</td><td>4</td></tr>
</table>

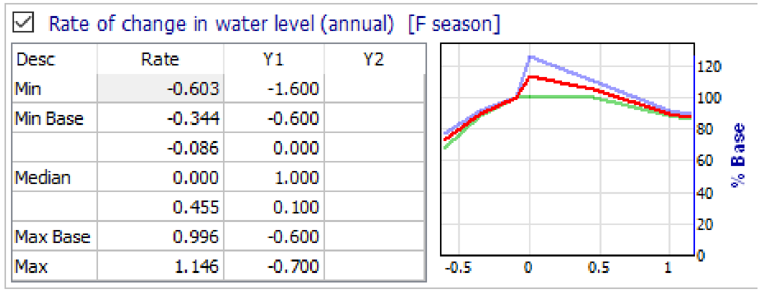
<table>
<tr><td colspan="2">Wetlands & Pans associated with the lake</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ VerDist from water level to fixed (amsl) tree-line [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.007</td><td>1.100</td><td></td></tr>
<tr><td>Min Base</td><td>0.000</td><td>0.900</td><td></td></tr>
<tr><td></td><td>0.734</td><td>0.400</td><td></td></tr>
<tr><td>Median</td><td>1.474</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.801</td><td>-0.800</td><td></td></tr>
<tr><td>Max Base</td><td>4.127</td><td>-1.000</td><td></td></tr>
<tr><td>Max</td><td>4.747</td><td>-1.200</td><td></td></tr>
</table>

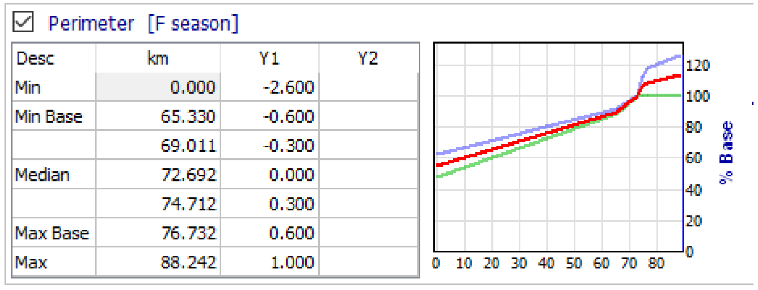
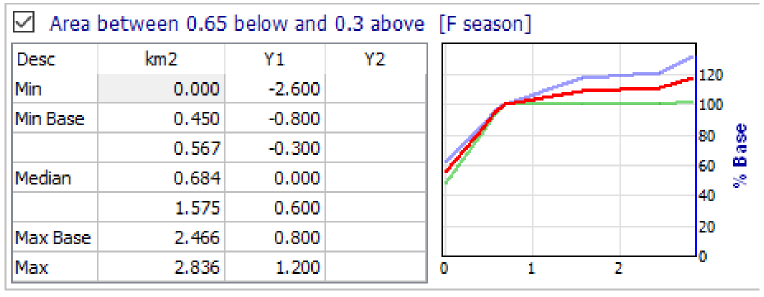
</td><td>The wetlands and pans surrounding the lake occur at varying levels above the lake level and may or may not become connected to the lake at high water levels. Nevertheless it is assumed (as with the lake) that water levels in wetlands and pans are an expression of localised ground water levels, but will also be affected by rainfall. Just as the lake water level maintains the clearly defined tree line by way of periodic inundation (about once a decade) of the areas up to where adult trees currently occur (at an average of 20.4 mamsl), the integrity of wetlands and pans will also be maintained by the same frequency and magnitude of inundation [at least]. Such inundation is important for the maintenance of non-woody species dominance and composition, and will keep wetlands and pans from becoming invaded by woody vegetation. Wetland and pan condition was therefore linked to vertical distance above lake level (relative to the tree line at 20.39 mamsl) since this will likely reflect relative changes in ground water depth. A decreasing lake level is therefore taken to reflect an overall average increasing depth to ground water, which will result in differential drying of wetlands and pans. Such deterioration of wetland and pan condition will result in changes to vegetation composition and structure, with terrestrial species variously replacing wetland species.</td><td>3</td></tr>
</table>

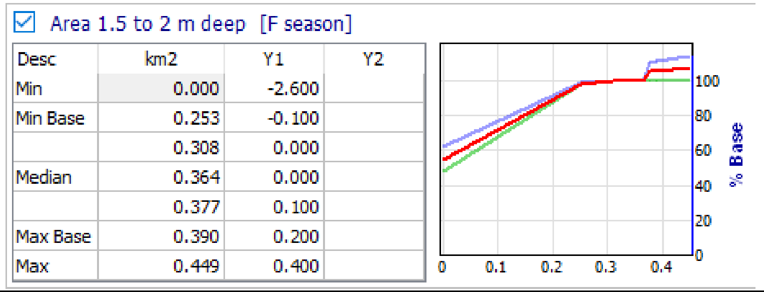
4.9.5 EWR Zone 5 – Western Arm

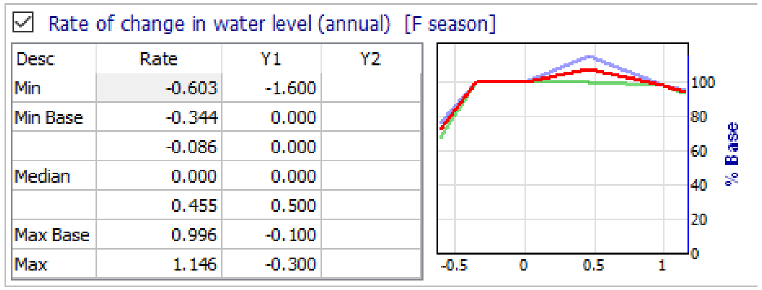
<table>
<tr><td colspan="2">Free floating vegetation</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Vol where DIN ~0.23mg/l [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.400</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.600</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.600</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.400</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.400</td><td></td></tr>
</table>
</td><td>It is assumed that there will not be concentration changes related to lake level (see water quality rationale) but that flushes of nutrients entering the lake are localised and non-flow related and will not alter the oligotrophic nature of the lake. Concentrations were found to be higher however in shallower water (up to 2m in depth) and this value of 0.23mg/l was used here as an indicator rather than the lower value on 0.07mg/l for deeper water. Since growth of *Azolla* and *Pistia* is possible at these levels of nutrients it is assumed that free floating vegetation has to potential to increase if the volume of water with these levels of nutrients also increases.</td><td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Submerged aquatic macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area 0 to 7 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.700</td><td></td></tr>
<tr><td>Min Base</td><td>4.790</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>4.883</td><td>-0.100</td><td></td></tr>
<tr><td>Median</td><td>4.976</td><td>0.000</td><td></td></tr>
<tr><td></td><td>5.701</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>6.425</td><td>1.600</td><td></td></tr>
<tr><td>Max</td><td>7.389</td><td>2.100</td><td></td></tr>
</table>
</td><td>Allanson (1979) found submerged macrophytes ringing the lake from depths of 1m to 7m and at this time the 1% level for white light was at 12m. Previously submerged macrophytes were found at depths of 9 to 12m (Boltt *et al*. 1969; Hill *et al*. 1975 in Bruton & Cooper 1980). When turbidity increased during high water levels however, submerged macrophytes were only found to depths of 5.5m and photosynthetically active radiation to 7 to 8m (Allanson 1979). During the field visit in July 2015 submerged macrophytes were found to occur from the water's edge to at least 2.5m, but it was not possible to sample greater depths. The relationship of submerged macrophytes to habitable area (0-7m depth, depending on turbidity) is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>4</td></tr>
</table>

<table>
<tr><td colspan="2">Submerged aquatic macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.600</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>1.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>-0.600</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-0.700</td><td></td></tr>
</table>
</td>
<td>It is likely that submerged macrophytes as a zone (0 to -7m water depth) will be able to shift relatively rapidly (within a growing season) if the rate of change in water level is slow. [Myriophyllum spicatum for example is able to achieve root growth rates of up to 1cm/day (Hussner *et al*. 2009)]. Conversely, the width of the zone is likely to shrink if rates of change are faster than the ability of plants to colonise newly available habitat. The critical rate of change of water level has been arbitrarily set at 0.5m per year. Rapid inundation to 0.5m is likely to result in a rapid increase in growth, but inundation beyond 1m is likely to reduce it. [Zhang *et al*. (2015) showed that the amplitude of water level fluctuation was the major determinant of M. spicatum biomass in various floodplain lakes].</td>
<td>4</td></tr>
</table>

<table>
<tr><td colspan="2">Emergent macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Perimeter [F season]
<table>
<tr><th>Desc</th><th>km</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>65.330</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>69.011</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>72.692</td><td>0.000</td><td></td></tr>
<tr><td></td><td>74.712</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>76.732</td><td>0.600</td><td></td></tr>
<tr><td>Max</td><td>88.242</td><td>1.000</td><td></td></tr>
</table>
</td>
<td>The wetted perimeter represents an area of potentially available habitat for emergent macrophytes which were found to be variously present from 40cm above water level to depths of 2.2m in July 2015. Furthermore, analyses of current and historic satellite data (Google Earth (C)) revealed that emergent macrophytes, as a zone, could shift as the water's edge did (from January 2006 through November 2010 to June 2013) i.e. small shifts in a little as 3 years. The ability of emergent macrophytes to shift in accordance with lake level will depend on the rates of change of water level however, but the satellite data analyses mentioned above showed that emergent macrophytes were able to shift over a vertical gradient of 1.5m in 7 years (0.2m per year).</td>
<td>4</td></tr>
<tr><td>
☑ Area between 0.65 below and 0.3 above [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.450</td><td>-0.800</td><td></td></tr>
<tr><td></td><td>0.567</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>0.684</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.575</td><td>0.600</td><td></td></tr>
<tr><td>Max Base</td><td>2.466</td><td>0.800</td><td></td></tr>
<tr><td>Max</td><td>2.836</td><td>1.200</td><td></td></tr>
</table>
</td>
<td>Measurements in July 2015 found the optimal hydraulic habitat for emergent macrophytes as a group to be from 0.3m above water level (mortality of Schoenoplectus scirpoides was observed at 0.43m and 0.83m) to 0.65m below water level (S. scirpoides was found to a maximum depth of 2.28m). The relationship of emergent macrophyte abundance to habitable area is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td>
<td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Emergent macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Area 1.5 to 2 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.253</td><td>-0.100</td><td></td></tr>
<tr><td></td><td>0.308</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.364</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.377</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>0.390</td><td>0.200</td><td></td></tr>
<tr><td>Max</td><td>0.449</td><td>0.400</td><td></td></tr>
</table>

</td><td>Emergent macrophytes are able to successfully grow to depths of 2.3m below water level (maximum recorded in July 2015) and frequently do so were such depths occur close to the water's edge (usually within 3-5m), but where shallow water occurs beyond these distances (such as at the extremities in the Western Arm), emergent macrophytes do not continue to colonise open water areas.</td><td>3</td></tr>
<tr><td>

☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
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<tr><td>Min Base</td><td>-0.344</td><td>0.000</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
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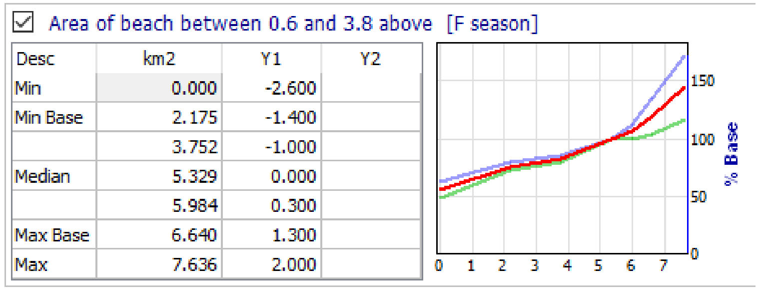
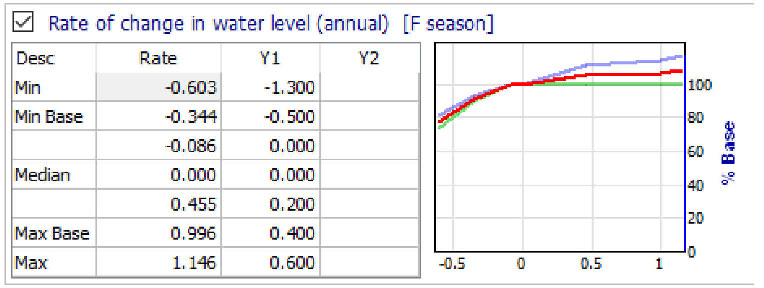
<tr><td>Max Base</td><td>0.996</td><td>-0.100</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-0.300</td><td></td></tr>
</table>

</td><td>Water level fluctuations were superimposed on satellite data (Google Earth) and related to emergent macrophyte zone integrity. Data showed that in exposed areas a rate of water level decline of 0.2m/year [or more] was associated with emergent macrophytes that were not able to track the declining shift in water level. In sheltered areas however, emergent macrophytes were able to shift with declining water level, up to a rate of 0.36m/year. Sample size was limited however which severely retards a better understanding of the exact relationship. The Western Arm was treated as having an abundance of sheltered sites. Rapid inundation to 0.5m is likely to result in a rapid increase in growth, but inundation beyond 1m is likely to reduce it.</td><td>3</td></tr>
</table>

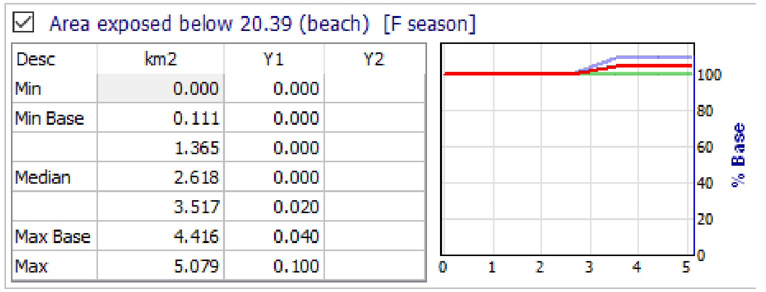
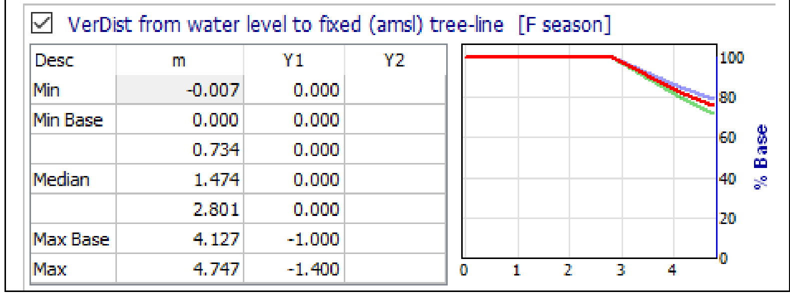
<table>
<tr><td colspan="2">Shore “beach” macrophytes</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Area of beach between 0.6 and 3.8 above [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.600</td><td></td></tr>
<tr><td>Min Base</td><td>2.175</td><td>-1.400</td><td></td></tr>
<tr><td></td><td>3.752</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>5.329</td><td>0.000</td><td></td></tr>
<tr><td></td><td>5.984</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>6.640</td><td>1.300</td><td></td></tr>
<tr><td>Max</td><td>7.636</td><td>2.000</td><td></td></tr>
</table>

</td><td>Measurements in July 2015 found the optimal hydraulic habitat for macrophytes on sandy "beach" areas as a group to be from 0.6m to 3.8m above water level (15.77 mamsl). The relationship of "beach" macrophyte abundance to habitable area is assumed to be proportional when the rates of change of water depth are slow, but this will not necessarily be the case if water levels rapidly change.</td><td>3</td></tr>
</table>

Shore "beach" macrophytes		
Response curve	Explanation	Confidence
	Rapid rates of increase are likely to cause some growth in the lower portions of the zone since most species representing this indicator are able to withstand and benefit from moderate inundation. Rapid rates of decline are likely to be detrimental to the zone with likely reductions in density. Rates of decline at or in excess of 0.5m per year will likely result in some desiccation stress, with associated reduction in density.	3

☑ Rate of change in water level (annual) [F season]

Desc	Rate	Y1	Y2
Min	-0.603	-1.300	
Min Base	-0.344	-0.500	
	-0.086	0.000	
Median	0.000	0.000	
	0.455	0.200	
Max Base	0.996	0.400	
Max	1.146	0.600	

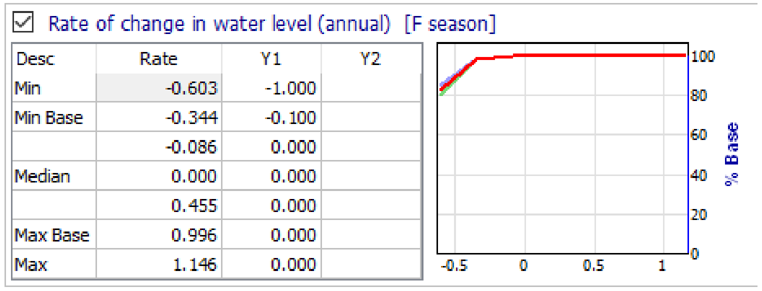
Woody "lake-dependent" vegetation		
Response curve	Explanation	Confidence
	The current tree line (indicated by Syzygium cordatum) is clearly defined by a distinct band of adult trees at about 20.4 mamsl. This clearly defined transition band is most likely maintained during periods of high lake levels which will cause mortality of trees colonising the beach area (from tree line to the water's edge). The records of lake level show that this occurs approximately every decade. During times of draw down when lake levels drop below about 20 mamsl the area of exposed beach will increase and become potential habitat for the colonisation of tree saplings, which will facilitate an expansion of the woody, lake-dependent vegetation, a phenomenon clearly observed to be in operation in July 2015.	4
	It is fair to assume that Syzygium cordatum is phreatophytic (due to its association with riparian zones, wetland fringes and other wetter areas) and therefore also drought-sensitive. Other, similar species such as Populus fremontii and Salix gooddingii have been shown to maintain dense, multi-aged stands where depth to ground water was less than 4m (Lite & Stromberg 2005). This general rule has been applied here to mark the point at which tree density and abundance is likely to decline due to desiccation stress.	4

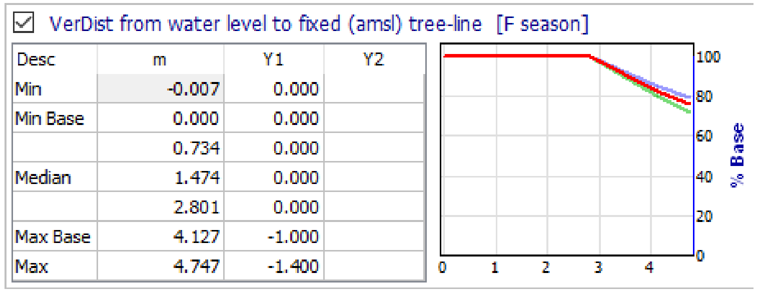
☑ Area exposed below 20.39 (beach) [F season]

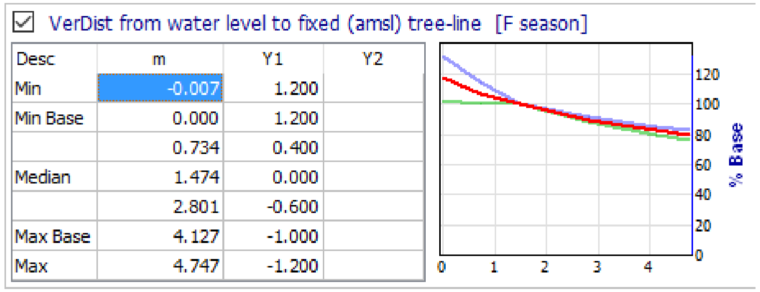
Desc	km2	Y1	Y2
Min	0.000	0.000	
Min Base	0.111	0.000	
	1.365	0.000	
Median	2.618	0.000	
	3.517	0.020	
Max Base	4.416	0.040	
Max	5.079	0.100	

☑ VerDist from water level to fixed (amsl) tree-line [F season]

Desc	m	Y1	Y2
Min	-0.007	0.000	
Min Base	0.000	0.000	
	0.734	0.000	
Median	1.474	0.000	
	2.801	0.000	
Max Base	4.127	-1.000	
Max	4.747	-1.400	

<table>
<tr><th colspan="2">Woody “lake-dependent” vegetation</th><th></th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.100</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>0.000</td><td></td></tr>
</table>
</td>
<td>Cottonwood-willow forests (Populus fremontii and Salix gooddingii) were shown to be dense and multi-aged where intra-annual ground-water fluctuation was between about 0.5 and 1m (Lite and Stromberg 2005). Again, S. cordatum is a similar phreatophyte, so the relationship was applied to rates of decline greater than 0.5m/year, where tree density would likely decline.</td>
<td>4</td></tr>
</table>

<table>
<tr><th colspan="2">Swamp Forest</th><th></th></tr>
<tr><th>Response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ VerDist from water level to fixed (amsl) tree-line [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.007</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.734</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>1.474</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.801</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>4.127</td><td>-1.000</td><td></td></tr>
<tr><td>Max</td><td>4.747</td><td>-1.400</td><td></td></tr>
</table>
</td>
<td>There were no elevation data available for swamp forest, but it is assumed here that Ficus trichopoda has comparable ability to utilise ground water than S. cordatum where it occurs. The same rule was thus applied as for S. cordatum in terms of distance to ground water (repeated here for clarity): It is fair to assume that Syzygium cordatum is phreatophytic (due to its association with riparian zones, wetland fringes and other wetter areas) and therefore also drought-sensitive. Other, similar species such as Populus fremontii and Salix gooddingii have been shown to maintain dense, multi-aged stands where depth to ground water was less than 4m (Lite & Stromberg 2005). This general rule has been applied here to mark the point at which tree density and abundance is likely to decline due to desiccation stress.</td>
<td>3</td></tr>
</table>

<table>
<tr><td colspan="2">Wetlands & Pans associated with the lake</td><td></td></tr>
<tr><td>Response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ VerDist from water level to fixed (amsl) tree-line [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.007</td><td>1.200</td><td></td></tr>
<tr><td>Min Base</td><td>0.000</td><td>1.200</td><td></td></tr>
<tr><td></td><td>0.734</td><td>0.400</td><td></td></tr>
<tr><td>Median</td><td>1.474</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.801</td><td>-0.600</td><td></td></tr>
<tr><td>Max Base</td><td>4.127</td><td>-1.000</td><td></td></tr>
<tr><td>Max</td><td>4.747</td><td>-1.200</td><td></td></tr>
</table>
</td><td>The wetlands and pans surrounding the lake occur at varying levels above the lake level and may or may not become connected to the lake at high water levels. Nevertheless it is assumed (as with the lake) that water levels in wetlands and pans are an expression of localised ground water levels, but will also be affected by rainfall. Just as the lake water level maintains the clearly defined tree line by way of periodic inundation (about once a decade) of the areas up to where adult trees currently occur (at an average of 20.4 mamsl), the integrity of wetlands and pans will also be maintained by the same frequency and magnitude of inundation [at least]. Such inundation is important for the maintenance of non-woody species dominance and composition, and will keep wetlands and pans from becoming invaded by woody vegetation. Wetland and pan condition was therefore linked to vertical distance above lake level (relative to the tree line at 20.39 mamsl) since this will likely reflect relative changes in ground water depth. A decreasing lake level is therefore taken to reflect an overall average increasing depth to ground water, which will result in differential drying of wetlands and pans. Such deterioration of wetland and pan condition will result in changes to vegetation composition and structure, with terrestrial species variously replacing wetland species.</td><td>3</td></tr>
</table>

4.10 Assumptions and limitations

- It is assumed that the oligotrophic nature of the lake will prevail and therefore that no algal blooms or increased nutrient loads that will benefit free floating vegetation and some littoral zone species will occur.
- It is assumed that Dune Forest is independent of lake level, and is rather dependent on rainfall and salt spray.
- Sampling depths for submerged aquatic macrophytes was limited to what was observable from a boat. In most cases windy circumstances meant that visibility was limited to about 2.5 m. It is assumed that submerged aquatic macrophytes utilise the photic zone to the full, which at Sibaya is about 7 m deep.

4.11 Important plant species associated with Lake Sibaya

Family	Naturalised	Species	Threat status	SA Endemic	Invasive Alien	Protected	Common Name/s
FABACEAE		*Acacia karroo*	LC	No			Sweet Thorn
POACEAE		*Andropogon eucomus*	LC	No			Snowflake Grass
AZOLLACEAE	*	*Azolla filiculoides*	Not Evaluated	No	cat 1		Water Fern
CASUARINACEAE	*	*Casuarina equisetifolia*	Not Evaluated	No	cat 2		Horsetail Tree
CERATOPHYLLACEAE		*Ceratophyllum demersum var. demersum*	LC	No			Water Hornwort
CYPERACEAE		*Cladium mariscus subsp. jamaicense*	LC	No			Saw Grass
THELYPTERIDACEAE		*Cyclosorus interruptus*	LC	No			
CYPERACEAE		*Cyperus articulatus*	LC	No			Jointed Flat Sedge
CYPERACEAE		*Cyperus natalensis*	LC	No			
CYPERACEAE		*Cyperus papyrus*	LC	No			Papyrus
CYPERACEAE		*Cyperus prolifer*	LC	No			Dwarf Papyrus
POACEAE		*Dactyloctenium geminatum*	LC	No			
MELASTOMATACEAE		*Dissotis canescens*	LC	No			
CYPERACEAE		*Eleocharis acutangula*	LC	No			
MORACEAE		*Ficus trichopoda*	LC	No		y	Swamp Fig
POACEAE		*Hemarthria altissima*	LC	No			Swamp Couch
ARALIACEAE		*Hydrocotyle bonariensis*	LC	No			Water Pennywort
POACEAE		*Imperata cylindrica*	LC	No			Cottonwool Grass
POACEAE		*Ischaemum fasciculatum*	LC	No			Hippo Grass
JUNCACEAE		*Juncus oxycarpus*	LC	No			
ONAGRACEAE		*Ludwigia octovalvis*	LC	No			Shrubby Ludwigia
HALORAGACEAE	*	*Myriophyllum spicatum*	?	No	weed (cat 1)		Spiked Water-milfoil
NAJADACEAE		*Najas marina subsp. armata*	LC	No			Saw Weed

Family	Naturalised	Species	Threat status	SA Endemic	Invasive Alien	Protected	Common Name/s
NYMPHAEACEAE		*Nymphaea nouchali var. caerulea*	LC	No			Blue Water Lily
POACEAE		*Phragmites australis*	LC	No			Common Reed
ARACEAE	*	*Pistia stratiotes*	Not Evaluated	No	weed (cat 1)		Water Lettuce
POTAMOGETONACEAE		*Potamogeton schweinfurthii*	LC	No			Broad-leaved Pondweed
MYRTACEAE	*	*Psidium guajava*	Not Evaluated	No	cat 2 / 3		Guava
CYPERACEAE		*Pycreus nitidus*	LC	No			
CYPERACEAE		*Pycreus polystachyos var. polystachyos*	LC	No			
CYPERACEAE		*Schoenoplectus scirpoides*	LC	No			
POTAMOGETONACEAE		*Stuckenia pectinatus*	LC	No			Fennel-leaved Pondweed
MYRTACEAE		*Syzygium cordatum subsp. cordatum*	LC	No			Waterberry
TYPHACEAE		*Typha capensis*	LC	No			Bulrush

4.12 Indicator guilds used in DRIFT and detail of species representing each guild

Indicator Guild	Species Pool	Common Name/s	Threat status	SA Endemic	Invasive Alien	Riparian Indicator*	Wetland Obligate	Protected
Aquatic vegetation (free floating)	*Azolla filiculoides*	Red Azolla, Water Fern	Not Evaluated	No	category 1	5	y	
	Pistia stratiotes	Water Lettuce	Not Evaluated	No	category 1	5	y	
Aquatic vegetation (submerged, rooted)	*Ceratophyllum demersum var. demersum*	Water Hornwort	LC	No		5	y	
	Myriophyllum spicatum	Spiked Water-milfoil	Not Evaluated	No	category 1	5	y	
	Najas marina subsp. armata	Saw Weed	LC	No		5		
	Nymphaea nouchali var. caerulea	Blue Water Lily	LC	No		5	y	
	Potamogeton schweinfurthii	Broad-leaved Pondweed	LC	No		5	y	
	Stuckenia pectinatus	Fennel-leaved Pondweed	LC	No		5	y	
Emergent macrophytes	*Cladium mariscus subsp. jamaicense*	Saw Grass	LC	No		4	y	
	Cyperus articulatus	Jointed Flat Sedge	LC	No		4	y	
	Cyperus papyrus	Papyrus	LC	No		4	y	
	Cyperus prolifer	Dwarf Papyrus	LC	No		4		
	Eleocharis acutangula		LC	No		4	y	
	Hydrocotyle bonariensis	Water Pennywort	LC	No		4	y	
	Ischaemum fasciculatum	Hippo Grass	LC	No		4	y	
	Ludwigia octovalvis	Shrubby Ludwigia	LC	No		4	y	
	Phragmites australis	Common Reed	LC	No		4	y	
	Pycreus nitidus		LC	No		4	y	
	Pycreus polystachyos var. polystachyos		LC	No		3		
	Schoenoplectus scirpoides		LC	No		4	y	

Indicator Guild	**Species Pool**	**Common Name/s**	**Threat status**	**SA Endemic**	**Invasive Alien**	**Riparian Indicator***	**Wetland Obligate**	**Protected**
	Typha capensis	Bulrush	LC	No		4	y	
Shore "beach" macrophytes	*Andropogon eucomus*	Snowflake Grass	LC	No		3	y	
	Cyperus natalensis		LC	No		3		
	Dactyloctenium geminatum		LC	No		3		
	Hemarthria altissima	Swamp Couch	LC	No		3	y	
	Imperata cylindrica	Cottonwool Grass	LC	No		3		
	Juncus oxycarpus		LC	No		4	y	
Woody "lake dependent" vegetation	*Acacia karroo*	Sweet Thorn	LC	No		1		
	Casuarina equisetifolia	Horsetail Tree	Not Evaluated	No	category 2	1		
	Psidium guajava	Guava	Not Evaluated	No	category 2 / 3	0		
	Syzygium cordatum subsp. cordatum	Waterberry	LC	No		4		
Swamp Forest	*Ficus trichopoda*	Swamp Fig	LC	No		4		y

Riparian Indicator*:
0 = terrestrial, but can be found in riparian zone/wetland/floodplain
1 = preferential riparian species
2 = upper zone riparian obligate / floodplain species / wetland obligate (temporary zone)
3 = lower zone riparian obligate / wetland obligate (seasonal zone) / hydrophyte
4 = marginal zone riparian obligate / rheophyte / helophyte / hydrophyte / wetland obligate (permanent zone) / sudd hydrophyte
5 = aquatic (epihydate, pleustophyte, vittate)

4.13 Raw data of upper and lower limits for different species relative to sea level (mamsl) and lake level (site specific)

Site	Limit	Species	mamsl	Rel to WL (at site) (m)	Note
Main Basin link	lower	*Andropogon eucomus*	16.638	0.865	
Main Basin link	lower	*Casuarina cunninghamiana_s*	16.746	0.973	saplings encroaching
Main Basin link	lower	*Cladium mariscus subsp. jamaicense*	16.228	0.455	
Main Basin link	lower	*Cladium mariscus subsp. jamaicense*	16.437	0.664	
Main Basin link	lower	*Cyperus natalensis*	16.035	0.262	
Main Basin (gps - S02)	lower	*Eleocharis acutangula*	14.273	-1.5	
Main Basin (gps - S02)	lower	*Juncus oxycarpus*	15.623	-0.15	
Main Basin link	lower	*Phragmites australis*	16.626	0.853	
Main Basin link	lower	*Potamogeton schweinfurthii*	15.473	-0.3	
Main Basin link	lower	*Pycreus polystachyos var. polystachyos*	15.884	0.111	pioneer colonisation
Main Basin link	lower	*Schoenoplectus scirpoides*	15.099	-0.674	
Main Basin link	lower	*Schoenoplectus scirpoides*	15.373	-0.4	
Main Basin link	lower	*Schoenoplectus scirpoides*	15.498	-0.275	
Main Basin link	lower	*Schoenoplectus scirpoides*	16.437	0.664	
Main Basin link	lower	*Stuckenia pectinatus*	15.473	-0.3	
Main Basin link	lower	*Typha capensis*	14.873	-0.9	
Main Basin link	lower	*Typha capensis*	14.916	-0.857	
Main Basin link	upper	*Cladium mariscus subsp. jamaicense*	16.713	0.94	
Main Basin link	upper	*Cyperus natalensis*	16.751	0.978	
Main Basin link	upper	*Phragmites australis*	17.255	1.482	
Main Basin link	upper	*Schoenoplectus scirpoides*	16.555	0.782	
Main Basin link	upper	*Schoenoplectus scirpoides_d*	16.619	0.846	Dead
Main Basin (gps - S02)	upper	*Stuckenia pectinatus*	15.773	0	
Main Basin link	upper	*Typha capensis*	16.673	0.9	
Northern Arm S 01	lower	*Cyperus natalensis*	17.738	1.965	
Northern Arm S 01	lower	*Eleocharis acutangula*	14.343	-1.43	
Northern Arm S 01	lower	*Eleocharis acutangula*	14.783	-0.99	
Northern Arm S 01	lower	*Eleocharis acutangula*	14.963	-0.81	
Northern Arm S 01	lower	*Ludwigia octovalvis*	15.173	-0.6	
Northern Arm S 01	lower	*Myriophyllum spicatum*	13.561	-2.212	
Northern Arm S 01	lower	*Myriophyllum spicatum*	13.883	-1.89	
Northern Arm S 01	lower	*Nymphaea nouchalia*	13.943	-1.83	
Northern Arm S 01	lower	*Potamogeton schweinfurthii*	14.573	-1.2	
Northern Arm S 01	lower	*Schoenoplectus scirpoides*	13.493	-2.28	
Northern Arm S 01	lower	*Schoenoplectus scirpoides*	14.193	-1.58	
Northern Arm S 01	lower	*Schoenoplectus scirpoides*	14.213	-1.56	
Northern Arm S 01	lower	*Schoenoplectus scirpoides*	14.828	-0.945	
Northern Arm S 01	lower	*Syzygium cordatum*	21.631	5.858	tree line
Northern Arm S 01	lower	*Typha capensis*	15.033	-0.74	
Northern Arm S 01	none	*Wl*	15.773	0	
Northern Arm S 01	upper	*Cyperus natalensis*	20.631	4.858	
Northern Arm S 01	upper	*Eleocharis acutangula*	14.923	-0.85	
Northern Arm S 01	upper	*Eleocharis acutangula*	15.773	0	
Northern Arm S 01	upper	*Ludwigia octovalvis*	16.173	0.4	
Northern Arm S 01	upper	*Myriophyllum spicatum*	15.773	0	
Northern Arm S 01	upper	*Nymphaea nouchalia*	15.623	-0.15	
Northern Arm S 01	upper	*Potamogeton schweinfurthii*	15.573	-0.2	
Northern Arm S 01	upper	*Schoenoplectus scirpoides*	15.773	0	
Northern Arm S 01	upper	*Schoenoplectus scirpoides*	16.123	0.35	
SE Basin	lower	*Casuarina cunninghamiana*	17.778	3.318	adults
SE Basin	lower	*Casuarina cunninghamiana_s*	16.775	2.315	saplings encroaching
SE Basin	lower	*Cyperus natalensis*	16.469	2.009	
SE Basin	lower	*Juncus oxycarpus*	16.469	2.009	
SE Basin	lower	*Syzygium cordatum*	19.3	4.839	tree line
SE Basin	none	*Myriophyllum spicatum_d*	15.334	0.874	remnants 3 yrs ago

Site	**Limit**	**Species**	**mamsl**	**Rel to WL (at site) (m)**	**Note**
SE Basin	none	*Myriophyllum spicatum_dd*	15.875	1.415	remnants 5 yrs ago
SE Basin	upper	*Juncus oxycarpus*	16.775	2.315	
SW Basin	lower	*Andropogon eucomus*	16.395	0.622	
SW Basin	lower	*Cyperus articulatus*	15.623	-0.15	
SW Basin	lower	*Hydrocotyle bonariensis*	15.673	-0.1	
SW Basin	lower	*Ludwigia octovalvis*	15.273	-0.5	
SW Basin	lower	*Nymphaea nouchalia*	14.773	-1	
SW Basin	lower	*Nymphaea nouchalia*	15.406	-0.367	
SW Basin	lower	*Potamogeton schweinfurthii*	14.773	-1	
SW Basin	lower	*Potamogeton schweinfurthii*	15.173	-0.6	
SW Basin	lower	*Pycreus nitidus*	15.673	-0.1	
SW Basin	lower	*Schoenoplectus scirpoides*	13.573	-2.2	
SW Basin	lower	*Syzygium cordatum*	20.093	4.32	tree line
SW Basin	lower	*Typha capensis*	14.773	-1	
SW Basin	none	*Syzygium cordatum_s*	19.312	3.539	saplings have encroached and established to this point
SW Basin	none	*wl*	15.773	0	
SW Basin	upper	*Cyperus articulatus*	15.973	0.2	
SW Basin	upper	*Cyperus natalensis*	19.593	3.82	
SW Basin	upper	*Myriophyllum spicatum*	15.323	-0.45	
SW Basin	upper	*Nymphaea nouchalia*	15.773	0	
SW Basin	upper	*Potamogeton schweinfurthii*	15.573	-0.2	
SW Basin	upper	*Schoenoplectus scirpoides*	15.999	0.226	alive
SW Basin	upper	*Schoenoplectus scirpoides_d*	16.206	0.433	dead
Western Arm	lower	*Myriophyllum spicatum*	14.423	-1.35	
Western Arm	lower	*Nymphaea nouchalia*	14.823	-0.95	
Western Arm	lower	*Nymphaea nouchalia*	15.423	-0.35	
Western Arm	lower	*Schoenoplectus scirpoides*	14.233	-1.54	
Western Arm	lower	*Schoenoplectus scirpoides*	14.323	-1.45	
Western Arm	lower	*Schoenoplectus scirpoides*	14.373	-1.4	
Western Arm	lower	*Schoenoplectus scirpoides*	14.713	-1.06	
Western Arm	lower	*Schoenoplectus scirpoides*	14.743	-1.03	
Western Arm	lower	*Typha capensis*	14.833	-0.94	
Western Arm	lower	*Typha capensis*	15.423	-0.35	

4.1 References

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5 MACROCRUSTACEA AND MOLLUSCS

5.1 Introduction

This Section comprises the summary specialist report for the crustacean and molluscs, and provides:

- An overview of the study area, with focus on delineation of homogenous areas for crustacean and molluscs;
- For the EWR sites:
  - EcoClassification assessments for the crustacea and molluscs, with supporting evidence;
  - the DRIFT indicators chosen, and reasons therefore;
  - the relationships between your chosen indicators and water level or other drivers (you will describe these in the DRIFT DSS), with referenced, supporting motivations (see Table below- the figures will be available once the DRIFT DSS has been populated).
- Data and the details of any analyses performed.
- EcoSpecs and monitoring actions required to describe and monitor the recommended Ecological Status with respect to crustacea and molluscs.

5.2 Description of the study area with respect to crustacea and molluscs

Lake Sibaya is a Ramsar listed 'Wetland of International Importance' and is part of the iSimangaliso Wetland Park World Heritage Site. It is fed by groundwater from a local sand-aquifer. It has no rivers entering it (only some minor groundwater-fed streams) and so no or little sediment is transported into the lake. As a result the water is very clear (Figure 5.1) with low nutrients and little suspended solids. The lake is situated in a valley that was scoured out during past glacial periods when sea-levels were much lower than they are at present. Over the past 3000 to 6000 years the connection with the sea was blocked (Hill 1979) forming the freshwater lake present today and which contains some relict estuarine species as evidence of this former connection. The lake has an average surface area of 65 km^2 and a maximum depth of 41 m (Pitman & Hutchison 1975). The bed of the lake comprises homogenous medium-grained white sand, with some gyttja deposits (i.e. mud formed from partial decay of peat) in the deeper portions (Miller 2001).

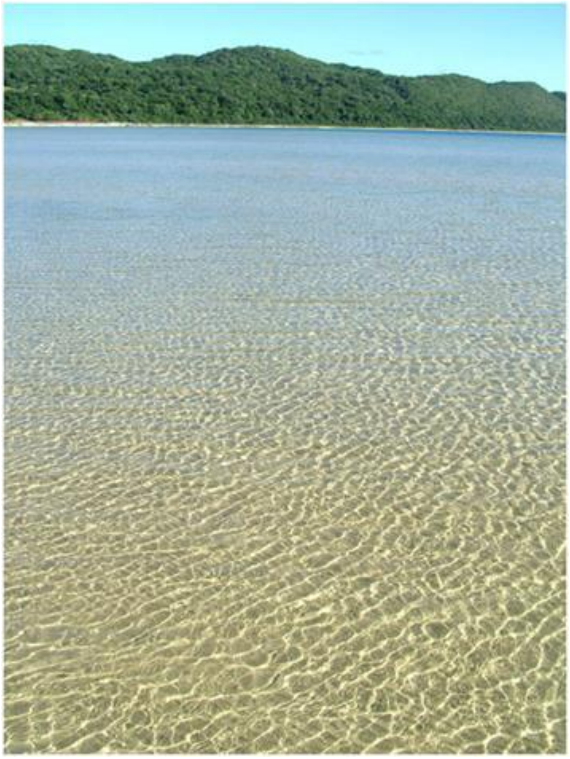


Figure 5.1 Sibaya Lake showing crystal-clear water and a white sandy substrate

5.3 Literature review

Detailed studies of the crustaceans and molluscs were conducted by various researchers associated with the Rhodes University Research Station in the 1970s. These are reported in Hart (1979; 1980). In addition, Appleton (1977 & 1980) has conducted studies on the non-marine molluscs of the area. More recently, Miranda and Perissinotto (2012 & 2014) have conducted several studies on the alien snail, *Tarebia granifera* that has invaded the shallow portions of the lake system, and now occurs in great abundance. These references were used extensively in compiling this report.

Lake Sibaya separated from the sea a few thousand years ago. It then became an endorheic freshwater system. As such, it has not been easy for species to colonise from other freshwater systems and the species that have been introduced are more likely to be generalists than specialists. The system does not have a great abundance of species and those considered here tend to be ones that occur in all the habitats of the lake.

A number of the macrocrustaceans (i.e. not the zooplankton or small benthic species) were considered in this study and the most distinctive were chosen as candidate species to indicate changes in water levels. The approach adopted to summarise their characteristics was to compile species fact-sheets from the literature associated with their life histories and biology. The work done by the above authors has been summarised, along with other data gathered, into the species fact-sheets provided in section 5.11.

The analysis of the macrocrustaceans and molluscs of Lake Sibaya is based on existing data from Hart (1979 and 1980), Appleton (1977 and 1980) and Miranda and Perissinotto (2012 & 2014) described above. The documents by Hart describe the intensive shoreline and scuba surveys carried out to characterise habitat selection and abundances of all the major invertebrates of Lake Sibaya.

5.4 Field data collection

The level of detailed work done by previous researchers described in Section 5.3 could not be replicated during this study so the focus was placed on determining whether the habitats described by Hart were still present as a proxy for the abundance of macrocustaceans.

The sites visited during the field survey in this study are shown in Figure 5.2. At each site the general ecological conditions were recorded and evidence of the main indicator species was noted. We particularly looked for any changes that may have occurred since the detailed studies were carried out as mentioned above.

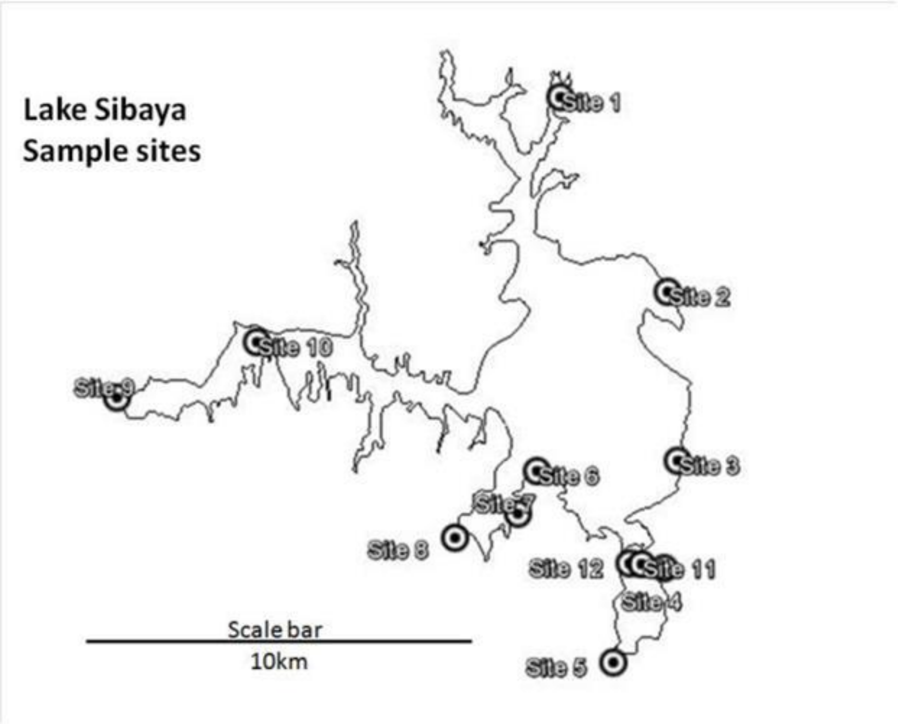


Figure 5.2 Location of the 10 sampling sites

5.5 Description of the EWR zones

Several distinct habitats for crustaceeans and molluscs are identified and described below:

- **Open water habitat**. This is the bulk of the lake. Its area and water volume varies with lake level. It is a deep system, but very well mixed with little stratification of temperature or oxygen (Allanson 1979a; 1979b). The water is extremely clear as it has very low quantities of suspended material in it and nutrient levels are also very low.
    - The lake reaches a depth of over 40 m (Hill 1979). The lake bed is homogenous, composed mainly of moderately fine white sand. In the deepest areas there is an accumulation of gyttja; a dark-grey organic mud (Miller 2001). The main basin is exposed to intense wind action which generates high-energy waves. The open water habitat can be divided into three main components:
    - The very deep gyttja deposits are not well suited as habitat for benthic animals due to their instability and relatively low oxygen levels.
    - The deep water sandy substrate areas are fairly homogenous throughout the lake. The depth to which light can effectively penetrate (for photosynthesis) is up to 7 m, being the photic zone beyond which there are no plants. Within the photic zone there are beds of submerged macrophytes dominated by an alien species *Myriophyllum spicatum*. These plants form important habitat for some species of crustaceans and molluscs.
    - There are shallow ‘terraces’ along the shoreline of the system (Figure 5.3). The depth of these terraces change in respond to changes in water level.
- **Shoreline habitat**. This is the lake margin; the interface between land and lake. It is divided into two components:
    - The vegetation-free high-energy shorelines, described by Hart (1979) and shown in Figure 5.4 is a harsh environment for crustaceans and molluscs.
    - The vegetated shorelines. These have a narrow band of emergent plants which create a habitat for many crustaceans and molluscs.
- **Basin-end swamps**. There are deep inlets (drowned inter-dune valleys), which accumulate organic matter at their distal ends (Figure 5.5). Here, protected from wave action and form sedge-swamps that are nutrient-rich areas inhabited by several types of molluscs and crustaceans.
- **Pans connected with the lake**. At relatively high lake levels the water rises to fill adjacent depressions, which may or may not become linked with the lake. If they are linked they can become rich habitats for molluscs and crustaceans especially if the water inundates marginal vegetation.

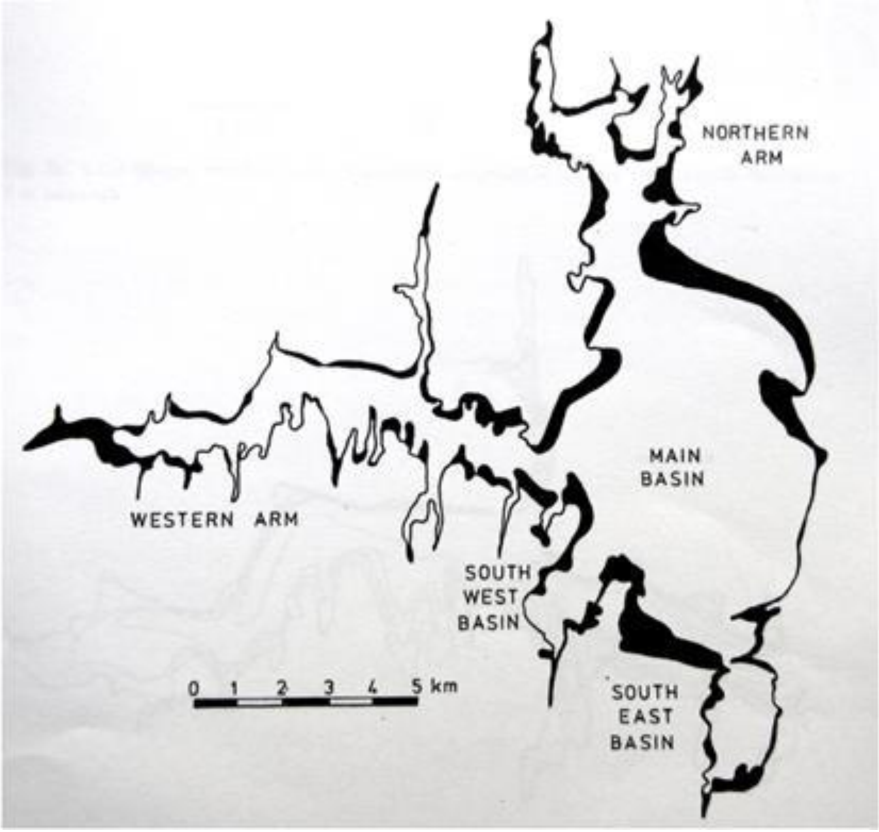
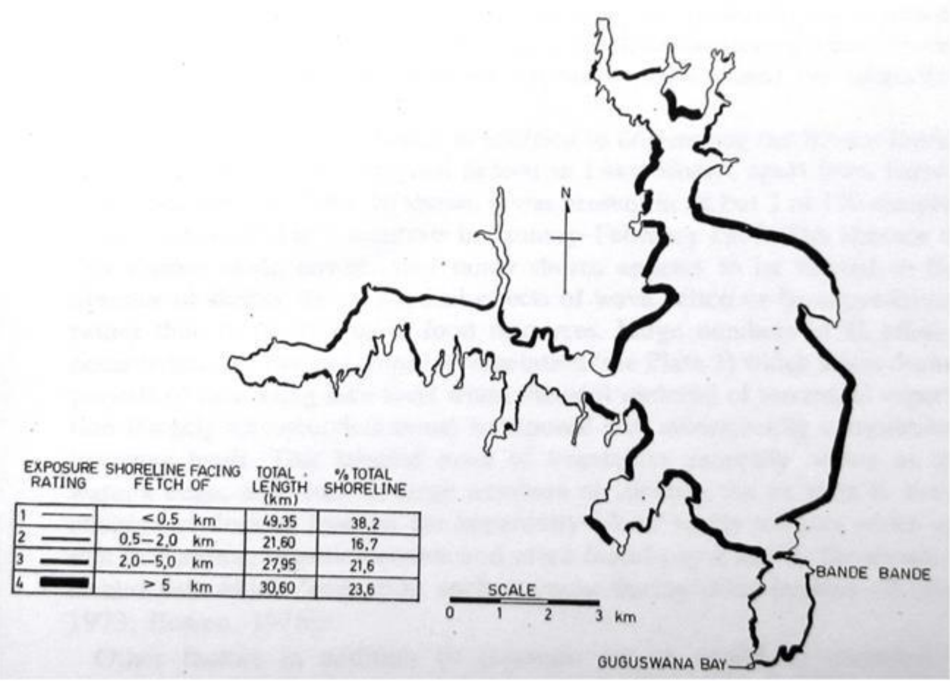


Figure 5.3 The locations of the main shallow-water terraces Hill (1979)



EXPOSURE RATING	SHORELINE FACING FETCH OF	TOTAL LENGTH (km)	% TOTAL SHORELINE
1 ─	< 0,5 km	49,35	38,2
2 ━	0,5–2,0 km	21,60	16,7
3 ━	2,0–5,0 km	27,95	21,6
4 ▬	> 5 km	30,60	23,6

Figure 5.4 Map showing exposure of shorelines to wave action (Hart 1979)

Figure 5.5 The distal ends of the inlets and embayments form a richly-vegetated habitat protected from wave action

5.5.1 EWR Zone 1 – South Basin

This is characterised by relatively exposed and bare shorelines with little emergent vegetation. The Southern portion of this basin (Guguswana Bay), where the main pump station is, has organic deposits with abundant swamp vegetation.

Figure 5.6 The beach at Bande Bande in the south Basin exposed to south winds and with no emergent vegetation

Figure 5.7 The sheltered pump-house showing rich growth of swamp vegetation and accumulation of organic deposits

5.5.2 EWR Zone 2 – Main Basin

The deepest part of the lake is located in the main basin but there are also characterised by large areas of shallow terraces. Much of the shoreline is exposed to wave action and, as a result, there is little marginal vegetation (Figure 5.8) other than in areas protected from the wind.

Figure 5.8 The wind-swept barren shoreline of the north-east portion of the Main Basin

The steep drop-off slopes forming the interface between the shallow and deep waters create a habitat where submerged macrophytes such as *Stuckenia pectinata* grow (Figure 5.9).

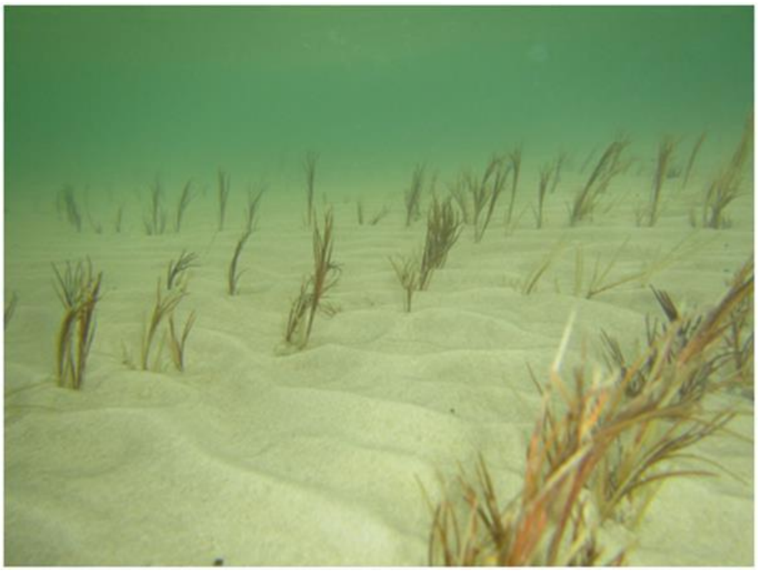


Figure 5.9 *Stuckenia pectinata* growing in shallow water in the Main Basin

5.5.3 EWR Zone 3 – Northern Arm

The Northern Arm has a convoluted shoreline and is reasonably sheltered from the wind. In addition the inlets have rich growth of plants at their distal ends. The site visited was at the northern pumphouse (Figure 5.10 and Figure 5.11).

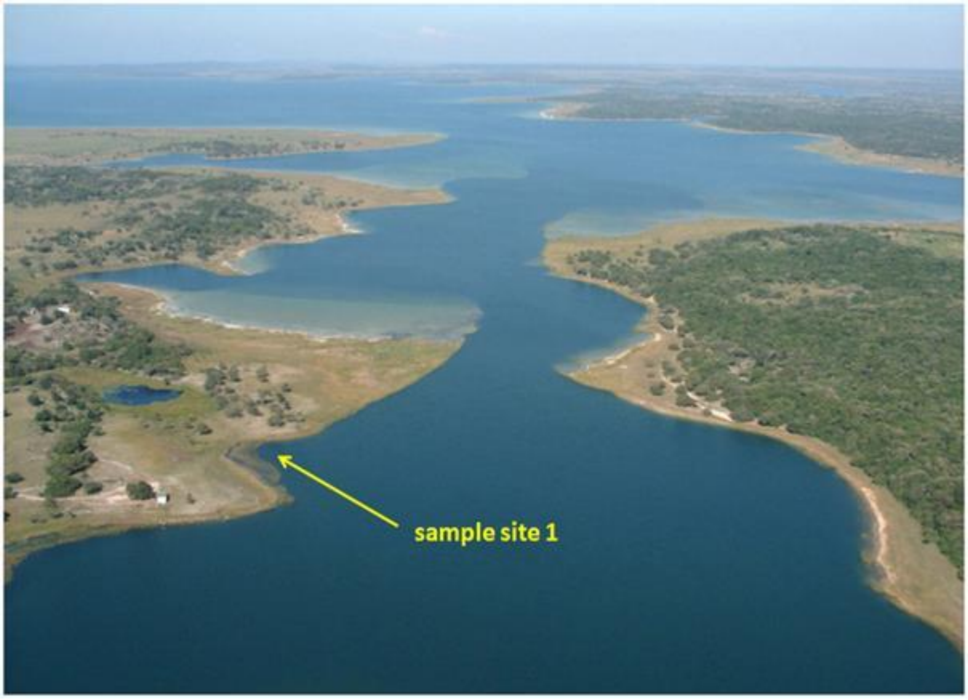


Figure 5.10 **An oblique aerial photo of the North Arm of the lake showing the location of the site visited (1)**

Figure 5.11 **Site 1 as seen on the ground – showing the narrow band of emergent vegetation**

5.5.4 EWR Zone 4 – Southwestern Basin

This is a relatively small basin with shorelines that are exposed to wind and wave action and some shoreline vegetation in protected areas.

5.5.5 EWR Zone 5 – Western Arm

The Western Arm is distinct from the rest of the lake being in an East-West orientation it is not as affected by the strong northerly and southerly winds as the rest of the system but is heavily influenced by residents of the Mseleni community, situated at the north west of the arm. There is an abundance of emergent vegetation and swamp at the shoreline (Figure 5.12) and distal ends of the inlets (which are drowned inter-dune valleys (Figure 5.13).

Figure 5.12 The highly enriched western end to the Western Arm showing the rich swamp vegetation and the exposed organic deposits covered with algae

Figure 5.13 The pan in the Southern part of the Western Arm in the an interdune valley

5.6 EcoClassification of the Lake represented by the EWR zones

The purpose of EcoClassification is to gain insights and understanding into the causes and sources of the deviation of the Present Ecological State (PES) of biophysical attributes from the Reference Condition (Kleynhans and Louw 2007). Although the lake is divided into five zones for the purpose of this study all the basins, with respect to crocodiles, hippos and frogs, were classified the same due to the mobility of these organisms and the connectivity of the lake zones.

The present baseline condition is one where there has been widespread infestation by the alien plant *Myriophyllum spicatum* sometime prior to the 1960s. This alien has added substantially to the extent of submerged vegetation. Another system-altering invasive alien species is the snail *Tarebia granifera* which is now also extremely abundant and widespread.

The **Reference Condition** is, however, considered to be that described above without the alien species.

This assessment rated the Lake as a Category C for molluscs and a B for crustaceans. The mollusc scores were lower due to the presence of the invading species *Tarebia granifera*. The EcoClassification for the lake overall, extrapolated to the five areas (EWR sites) is a **Category C**.

5.7 Results

The work done by the above authors has been summarised, along with other data gathered, into the species fact-sheets provided in Section 5.11. The field data are summarised in Table 5.1 below.

Table 5.1 Ranked abundance of species of macrocrustaceans at Lake Sibaya, this study (July 2015)

Area	Site No.	Date	*Tarebia granifera*	*Corbicula africana*	*Melanonoides tuberculatus*	*Biomphalaria pfeifferi*	*Bellamya capillata*	*Bulinus natalensis*	*Bulinus globosus*	*Caradina nilotica*	*Potamonautes sydneyi*	*Hymenosoma orbiculare*
North Arm	1a	14-Jul-15	4	0	0	0	0	0	1	2	1	0
North Arm	1b	14-Jul-15	2	0	0	0	0	0	0	0	1	0
Boat launch	2a	14-Jul-15	4	2	2	0	2	0	0	0	0	0
Offshore - near deep hole	2b	14-Jul-15	0	0	0	0	0	0	0	0	0	0
Old resarch Station	3	14-Jul-15	1	0	3	0	0	0	0	0	0	0
Banda Banda	4	14-Jul-15	4	0	2	0	0	0	0	0	0	0
SE Pumphouse	5	14-Jul-15	0	0	0	0	0	0	0	0	0	0
Baya Camp	6	15-Jul-15	2	2	0	0	2	0	0	0	1	1
Baya Camp - west	7a	15-Jul-15	3	0	0	0	0	2	0	0	3	0
End of bay	7b	15-Jul-15	4	0	0	0	0	0	0	0	0	0
End of bay - west	7c	15-Jul-15	3	0	0	0	2	0	0	3	0	0
Peninsula	7d	15-Jul-15	4	2	0	0	0	0	0	3	0	3
Sheltered side	7e	16-Jul-15	4	2	0	0	0	0	0	0	0	0
Long pan	8	16-Jul-15	0	0	0	0	0	0	0	0	0	0
Mseleni pump	9a	16-Jul-15	1	2	0	1	0	0	0	2	0	0
Mseleni pump - east	9b	16-Jul-15	4	3	0	1	2	0	1	2	0	0
West Arm (boat coll.)	10	16-Jul-15	0	0	0	0	2	0	0	0	0	0
Bande Bande - crossing - south	11	17-Jul-15	4	3	2	0	3	2	0	1	1	1
Bande Bande - crossing - north	12	17-Jul-15	3	0	0	0	0	0	0	0	0	0

5.8 Identification of crustacean and mollusc indicators

5.8.1 Indicator list for crustacean and molluscs

A list of crustacea and molluscs taxa selected as indicators and the reason for their selection is provided in Table 5.2 while their expected responses to changes in water level are described in Table 5.3.

Table 5.2 Indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Caridina nilotica	Are generalist species but will respond to changes in lake levels.
Hymenosoma orbiculare	
Potamonautes sidneyi	
Tarebia granifera	
Melanoides tuberculatus	
Bulinus (Physopsis) globosus	
Other pulmonate snails (e.g. *Lymnaea natalensis* , *Bulinus natalensis, Biomphalaria pfeifferi)*	

Table 5.3 List of crustacean indicators and their predicted direction of response to water level changes

Indicator	Definition	Predicted change	References
Caridina nilotica	A species that inhabits all habitats within the lake	Loss of lake area will reduce lake biomass	Hart 1979 &1980
Hymenosoma orbiculare	A species that inhabits all sandy areas – and some of the submerged macrophyte area	Loss of area will reduce lake biomass. Reduction in submerged macrophyte areas will reduce biomass	Hart 1979 &1980
Potamonautes sidneyi	Inhabits shoreline emergent vegetation	Loss of perimeter length – and loss of the vegetation will reduce numbers	Hart 1979 &1980; Bruton 1979

Table 5.4 List of mollusc indicators and their predicted direction of response to water level changes

Indicator	Definition	Predicted change	References
Tarebia granifera	Inhabits the photic zone (i.e. 0 to 7 m)	As the lake level drops a greater proportion of the remaining area will be inhabited by this species	Miranda & Perissinotto 2012 & 2014
Melanoides tuberculatus	Displaced by Tarebia granifera from the photic zone	As the lake level drops a smaller proportion of the remaining area will be inhabited by this species	Hart 1979 &1980, Appleton 1977, Appleton *et al.*2009.
Bulinus (Physopsis) globosus	Inhabits the vegetation fringing the lake shoreline.	Its overall numbers should decrease as shoreline length reduces – but the density of	Appleton 1977 & 1980.

Indicator	Definition	Predicted change	References
	It is an intermediate host for urinary bilharzia (Schistosoma haemotobium)	snails per unit length of shoreline is not affected.	
Other pulmonate snails (e.g. *Lymnaea natalensis* , *Bulinus natalensis,* *Biomphalaria pfeifferi)*	Inhabit the vegetation fringing the lake shoreline.	Overall numbers should decrease as shoreline length reduces – but the density of snails per unit length of shoreline is not affected.	Appleton 1977 & 1980.

5.8.2 Description and habitat of indicator species

5.8.2.1 *Caridina nilotica*

Habitat: Throughout the lake on sandy substrates and associated with submerged and emergent vegetation and peripheral pans.
Representative species: *Caridina nilotica*.
Other characteristic species: Virtually all the species are affected. Other species include *Melanoides tuberculatus*, *Corbicula africana* and *Bellamya capillata*
Water level-related concerns: Reduced depth reduces the overall lake biomass of this species.

5.8.2.2 *Hymenosoma orbiculare*

Habitat: It has no depth constraints (Hart 1979), but does not occur in the areas with silty substrates. It is more abundant where there are submerged macrophytes.
Representative species: *Hymenosoma orbiculare*
Other characteristic species: N/A
Water level-related concerns: A lowering of the water level reduces area available.

5.8.2.3 *Potamonautes sidneyi*

Habitat: The lake shoreline where there is emergent vegetation.
Representative species: *Potamonautes sidneyi*.
Other characteristic species: *Bullia globosus* and other pulmonate snails.
Water level-related concerns: The vegetation growth may be affected if the rate of water level change exposes and inundates the marginal vegetation too frequently.

5.8.2.4 *Name: Tarebia granifera*

Habitat: Shallow sheltered pans.
Representative species: *Tarebia granifera*.
Other characteristic species: *Caridina nilotica, Bullinus globosus.*
Water level-related concerns: A lowered lake level will mean that the connectivity with these pans will happen infrequently and they may dry as a result.

5.8.2.5 Melanoides tuberculatus

Habitat: Throughout the system – but numbers have been reduced by competition with *Tarebia granifera*
Representative species: *Melanoides tuberculatus*
Other characteristic species: *Bellamya capillata*
Water level-related concerns: A drop in water level will reduce the area of available habitat.

5.8.2.6 Bulinus (Physopsis) globosus

Habitat: The interface between lake and land that is the most biodiversity-rich habitat of the lake, as well as submerged stands of macrophytes. Shallow sheltered pans linked to the lake.
Representative species: *Bulinus globosus.*
Other characteristic species: Other pulmonate snails.
Water level-related concerns: Lowered water levels reduce habitat. Disconnection from the adjacent pans reduces the area available for this species

5.8.2.7 Other pulmonate snails

Habitat: Emergent and submerged vegetation
Representative species: *Bulinus natalensis, Lymnaea natalensis, Biomphalaria pfeifferi.*
Other characteristic species: *Bulinus globosus*
Water level-related concerns: The vegetation growth is likely to be affected by any increased rate of water level change which exposes and inundates the marginal vegetation too frequently.

5.8.2.8 Additional details for key taxa

All the taxa are expected to be affected by changes in water quality which alter levels of productivity and may flip the ecosystem to a phytoplankton-dominated system. All taxa will also be affected by pollution with pesticides, herbicides and molluscicides.

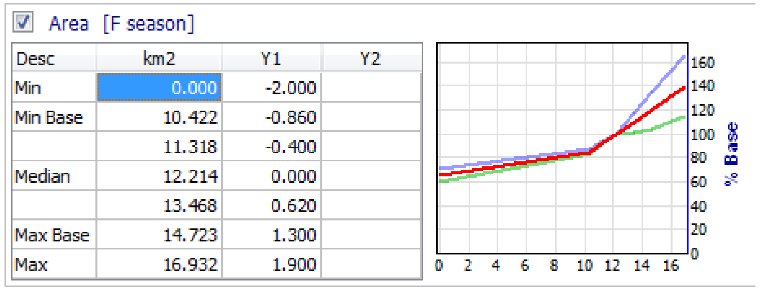
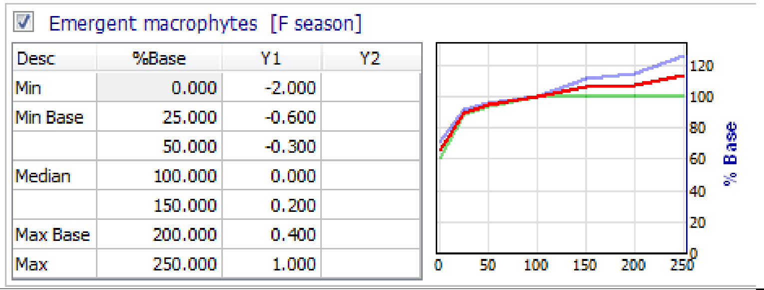
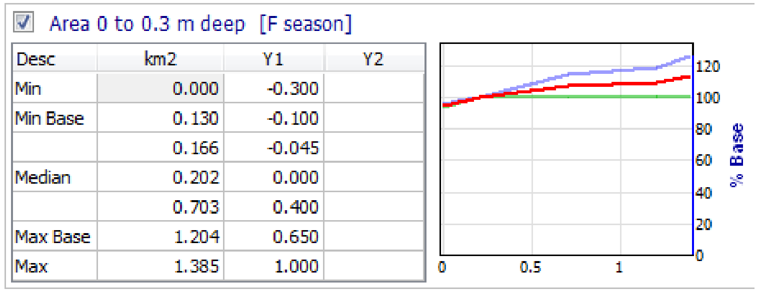
5.8.3 Linked indicators

Table 5.5 Linked indicators and motivation

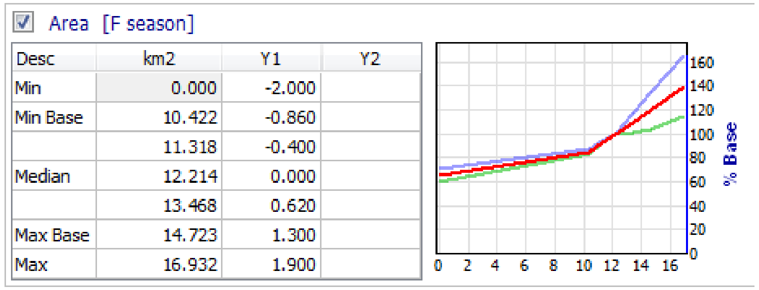
Indicator	Linked indicator	Motivation
Caridina nilotica	Area Emergent macrophytes Area 0 to 0.3 m deep	They are widespread – loss of area causes loss of total biomass. This is an important habitat – especially in the detritus-rich rootstock and shoreline wrack The newly-flooded area is a warm, food-rich and protected habitat
Hymenosoma orbiculare	Area Submerged, rooted vegetation	They are widespread – loss of area causes loss of total biomass. They live in the sand everywhere, but in greater numbers where there is submerged vegetation
Potamonautes sidneyi	Emergent macrophytes 0.5 to 1 m deep	This is an important habitat – especially in the detritus-rich rootstock. They burrow on the land-side of the vegetation Many of the young are in shallow water on the outer fringe of the vegetation
Tarebia granifera	Emergent macrophytes Area 0 to -7 m deep Area 0 to 0.3 m deep	This is an important habitat – especially in the detritus-rich rootstock. They live mainly in the photic zone – where they feed on diatoms in the surface of the sand The newly-flooded area is a warm, food-rich and protected habitat
Melanoides tuberculatus	Area deeper than 7 m	*Tarebia granifera* does seem to have displaced the Melanoides from the photic zone
Bulinus (Physopsis) globosus	Emergent macrophytes Area 0 to 0.3 m deep	This is an important habitat – especially on the submerged stems and leaves. The newly-flooded area is a warm, food-rich and protected habitat
Other pulmonate snails (e.g. *Lymnaea natalensis* , *Bulinus natalensis, Biomphalaria pfeifferi)*	Submerged, rooted vegetation Emergent macrophytes Area 0 to 7 m deep	They live on the stems and leaves of submerged plants This is an important habitat – especially on the submerged stems and leaves. They are absent in very deep water

5.9 Motivations for Response Curves

5.9.1 *Caridina nilotica*

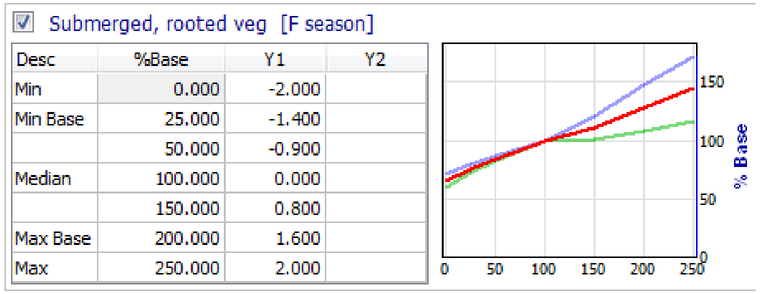
<table>
<tr><td colspan="2">Name: <i>Caridina nilotica</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>10.422</td><td>-0.860</td><td></td></tr>
<tr><td></td><td>11.318</td><td>-0.400</td><td></td></tr>
<tr><td>Median</td><td>12.214</td><td>0.000</td><td></td></tr>
<tr><td></td><td>13.468</td><td>0.620</td><td></td></tr>
<tr><td>Max Base</td><td>14.723</td><td>1.300</td><td></td></tr>
<tr><td>Max</td><td>16.932</td><td>1.900</td><td></td></tr>
</table>
</td>
<td>Occurs at all habitats except the exposed shorelines - with an average density of 2845 mg per sq m (Hart 1979). Modifier: a short-lived 'r'-selected species responds rapidly.</td><td>High</td></tr>
<tr><td>
☑ Emergent macrophytes [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.400</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.000</td><td></td></tr>
</table>
</td>
<td>Variable densities in the emergent vegetation, but averaging at fairly high densities (ave = 3x). Taken shore as 25 km at base level and vege width as 3 m = approx .75 km sq i.e. 1/20th of total area i.e. number = 3sq km of lake</td><td>Moderate</td></tr>
<tr><td>
☑ Area 0 to 0.3 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.300</td><td></td></tr>
<tr><td>Min Base</td><td>0.130</td><td>-0.100</td><td></td></tr>
<tr><td></td><td>0.166</td><td>-0.045</td><td></td></tr>
<tr><td>Median</td><td>0.202</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.703</td><td>0.400</td><td></td></tr>
<tr><td>Max Base</td><td>1.204</td><td>0.650</td><td></td></tr>
<tr><td>Max</td><td>1.385</td><td>1.000</td><td></td></tr>
</table>
</td>
<td>Caridina are abundant in the shallow water of newly-flooded areas of the shore. Hart (1979) gives varying abundances - averaging at about double that of the lake per sq km. This is about 1/60 th of the total importance of the whole lake.</td><td>Moderate</td></tr>
</table>

5.9.2 *Hymenosoma orbiculare*

<table>
<tr><td colspan="2">Name: <i>Hymenosoma orbiculare</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


☑ Area [F season]

<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>10.422</td><td>-0.860</td><td></td></tr>
<tr><td></td><td>11.318</td><td>-0.400</td><td></td></tr>
<tr><td>Median</td><td>12.214</td><td>0.000</td><td></td></tr>
<tr><td></td><td>13.468</td><td>0.620</td><td></td></tr>
<tr><td>Max Base</td><td>14.723</td><td>1.300</td><td></td></tr>
<tr><td>Max</td><td>16.932</td><td>1.900</td><td></td></tr>
</table>

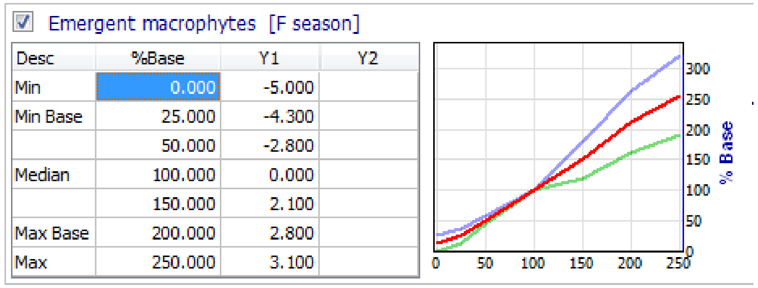
</td><td>Lives on sandy bottoms - so everywhere except on deep silty sediments Hart (1979)</td><td>High</td></tr>
<tr><td>


☑ Submerged, rooted veg [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.400</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.900</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.800</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.600</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.000</td><td></td></tr>
</table>

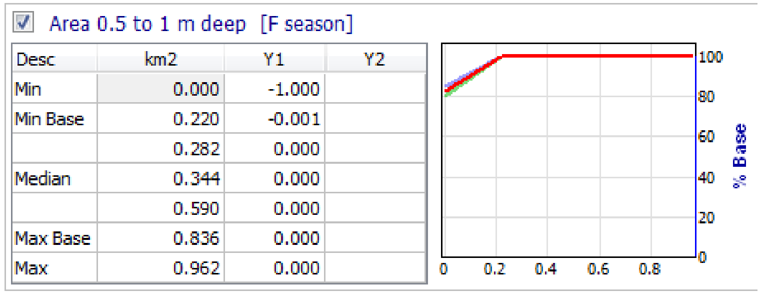
</td><td>Associated with submerged macrophytes (Hart 1979)</td><td>Moderate</td></tr>
</table>

5.9.3 *Potamonautes sidneyi*

<table>
<tr><td colspan="2">Name: <i>Potamonautes sidneyi</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


☑ Emergent macrophytes [F season]

Desc	%Base	Y1	Y2
Min	0.000	-5.000	
Min Base	25.000	-4.300	
	50.000	-2.800	
Median	100.000	0.000	
	150.000	2.100	
Max Base	200.000	2.800	
Max	250.000	3.100	

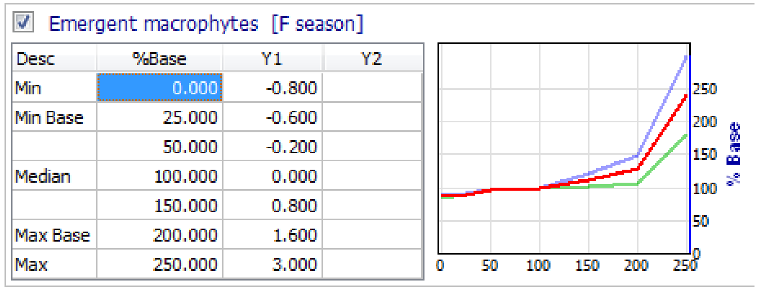
</td><td>Numbers directly related to area of emergent vegetation. Hart (1979) gives densities of 0.6 individuals per sq m.</td><td>High</td></tr>
<tr><td>


☑ Area 0.5 to 1 m deep [F season]

Desc	km2	Y1	Y2
Min	0.000	-1.000	
Min Base	0.220	-0.001	
	0.282	0.000	
Median	0.344	0.000	
	0.590	0.000	
Max Base	0.836	0.000	
Max	0.962	0.000	

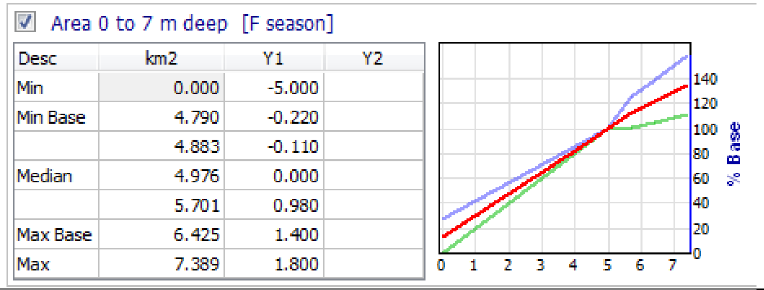
</td><td>In the vegetation linked to this level.</td><td>Low</td></tr>
</table>

5.9.4 *Tarebia granifera*

<table>
<tr><td colspan="2">Name: *Tarebia granifera*</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


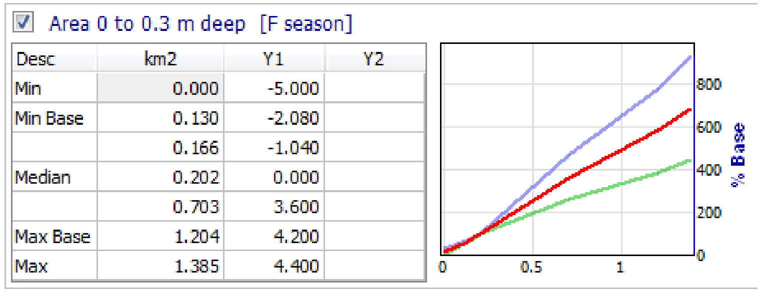
☑ Emergent macrophytes [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.800</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.800</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.600</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.000</td><td></td></tr>
</table>

</td><td>Associated with emergent macrophytes</td><td>Moderate</td></tr>
<tr><td>


☑ Area 0 to 7 m deep [F season]

<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>4.790</td><td>-0.220</td><td></td></tr>
<tr><td></td><td>4.883</td><td>-0.110</td><td></td></tr>
<tr><td>Median</td><td>4.976</td><td>0.000</td><td></td></tr>
<tr><td></td><td>5.701</td><td>0.980</td><td></td></tr>
<tr><td>Max Base</td><td>6.425</td><td>1.400</td><td></td></tr>
<tr><td>Max</td><td>7.389</td><td>1.800</td><td></td></tr>
</table>

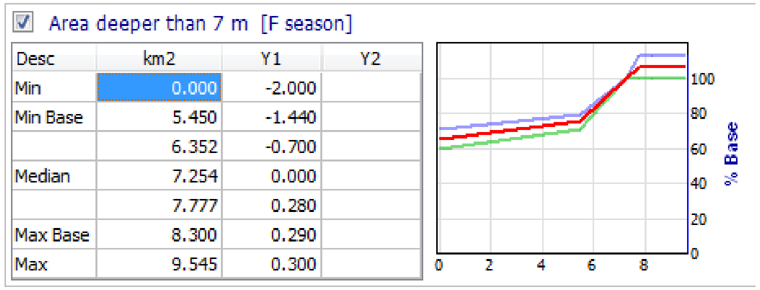
</td><td>In photic zone where it feeds on diatoms and detritus in the sand</td><td>Moderate</td></tr>
<tr><td>


☑ Area 0 to 0.3 m deep [F season]

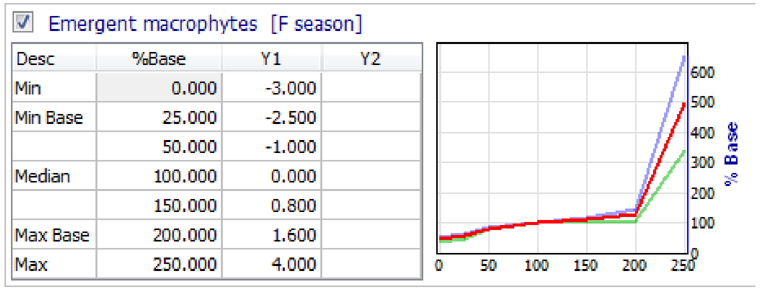
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.130</td><td>-2.080</td><td></td></tr>
<tr><td></td><td>0.166</td><td>-1.040</td><td></td></tr>
<tr><td>Median</td><td>0.202</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.703</td><td>3.600</td><td></td></tr>
<tr><td>Max Base</td><td>1.204</td><td>4.200</td><td></td></tr>
<tr><td>Max</td><td>1.385</td><td>4.400</td><td></td></tr>
</table>

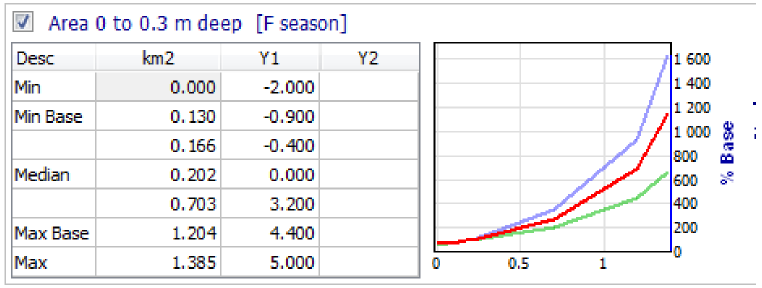
</td><td>Colonises shallow flooded areas in large numbers</td><td>Moderate</td></tr>
</table>

5.9.5 *Melanoides tuberculatus*

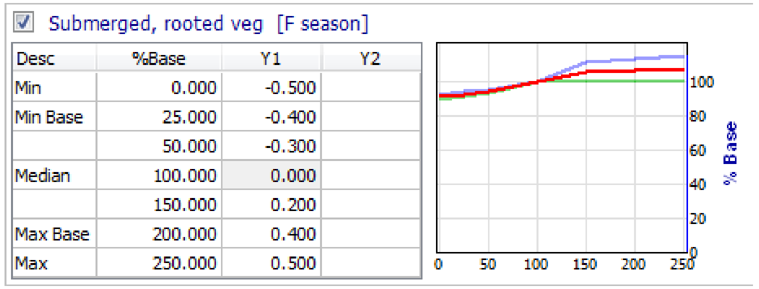
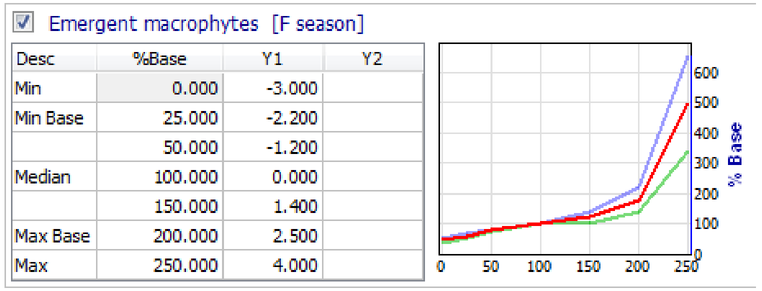
<table>
<tr><td colspan="2">Name: <i>Melanoides tuberculatus</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area deeper than 7 m [F season]
<table>
<tr><td>Desc</td><td>km2</td><td>Y1</td><td>Y2</td></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>5.450</td><td>-1.440</td><td></td></tr>
<tr><td></td><td>6.352</td><td>-0.700</td><td></td></tr>
<tr><td>Median</td><td>7.254</td><td>0.000</td><td></td></tr>
<tr><td></td><td>7.777</td><td>0.280</td><td></td></tr>
<tr><td>Max Base</td><td>8.300</td><td>0.290</td><td></td></tr>
<tr><td>Max</td><td>9.545</td><td>0.300</td><td></td></tr>
</table>
</td><td>Evenly distributed throughout the lake (Hart 1979) but displaced from photic zone by Tarebia (R Taylor, pers. obs.). Tends to cope with high-energy shorelines better than Tarebia (R Taylor pers. obs.).</td><td>Low</td></tr>
</table>

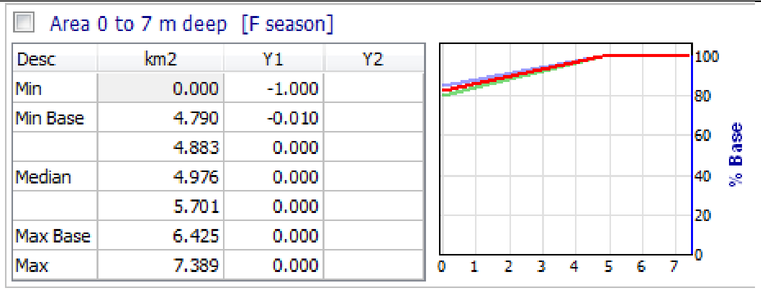
5.9.6 *Bulinus globifera*

<table>
<tr><td colspan="2">Name: <i>Bulinus globifera</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Emergent macrophytes [F season]
<table>
<tr><td>Desc</td><td>%Base</td><td>Y1</td><td>Y2</td></tr>
<tr><td>Min</td><td>0.000</td><td>-3.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.800</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.600</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>4.000</td><td></td></tr>
</table>
</td><td>Appleton (1977) says this species lives predominantly on emergent vegetation.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Name: <i>Bulinus globifera</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area 0 to 0.3 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.130</td><td>-0.900</td><td></td></tr>
<tr><td></td><td>0.166</td><td>-0.400</td><td></td></tr>
<tr><td>Median</td><td>0.202</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.703</td><td>3.200</td><td></td></tr>
<tr><td>Max Base</td><td>1.204</td><td>4.400</td><td></td></tr>
<tr><td>Max</td><td>1.385</td><td>5.000</td><td></td></tr>
</table></td><td>Colonises inundated grassland (Appleton 1977) - this can be in large numbers. This is a habitat that 'switches' on and off. When on, the total population level increases markedly</td><td>Low</td></tr>
</table>

5.9.7 Pulmonate snails (excluding *Bulinus globosus*)

<table>
<tr><td colspan="2">Name: Pulmonate snails (excluding <i>Bulinus globosus</i>).</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Submerged, rooted veg [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.400</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.400</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.500</td><td></td></tr>
</table></td><td>Pulmonate snails are mainly on submerged and emergent vegetation (Hart 1979).Bulinus natalensis is regarded as being 'a 'slow-growing' species that takes 6 months to reach maturity - the others can have 3 generations per year.(Appleton 1977)</td><td>High</td></tr>
<tr><td>
☑ Emergent macrophytes [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.200</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.400</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>4.000</td><td></td></tr>
</table></td><td>Pulmonate snails are mainly on submerged and emergent vegetation (Hart 1979).</td><td>High</td></tr>
</table>

Name: Pulmonate snails (excluding *Bulinus globosus*).		
Linked indicator response curve	Explanation	Confidence
	The change in water area has a fairly small effect at 'normal' water levels - but does come into play at extreme conditions.	Low

☐ Area 0 to 7 m deep [F season]

Desc	km2	Y1	Y2
Min	0.000	-1.000	
Min Base	4.790	-0.010	
	4.883	0.000	
Median	4.976	0.000	
	5.701	0.000	
Max Base	6.425	0.000	
Max	7.389	0.000	

5.10 Assumptions and limitations

1. We assume that the patterns of species distribution and their habitats described in the comprehensive early work done in the 1970's are similar to those in the current status.
2. The main difference observed in this study is the increased abundance of the snail *Tarebia granifera* in the shallow waters of the lake. This species has been studied in detail in the Lake by Miranda and Perissinotto (2012 & 2014). The data collected during this study showed little overlap between *Melanoides* and *Tarebia*, and it has been assumed that *Tarebia* have displaced *Melanoides* in the photic zone (i.e. 0 to 7 m) where the *Tarebia* are feeding on diatoms in the sand (Figure 5.14).

Figure 5.14 *Tarebia granifera* shells washed up on the shoreline of the Main Basin, Lake Sibaya

3. It has also been assumed that when water levels are high and flood the shallow pans connected to the lake the vegetation of the pans dies back and this provides an extremely rich habitat for the *Bulinus globifera* snail (Appleton 1980) and other species, such as *Tarebia*, which are pioneer species.

5.11 Species fact sheets

5.11.1 *Caridina nilotica*

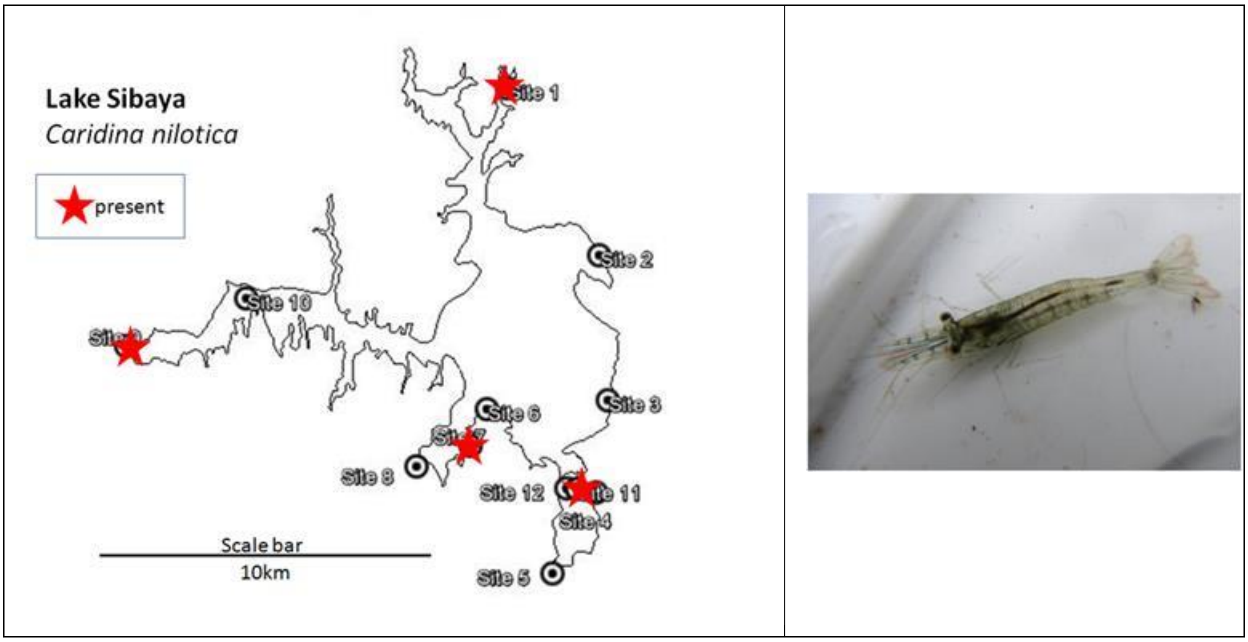


Figure 5.15 Distribution of *Caridina nilotica* in the lake and photograph

<u>Species description</u>

Small shrimp with an average size of about 3 cm long.

<u>Distribution and abundance (in particular depth-related limitations to spatial distribution)</u>

It occurs throughout the system as a common/important species (Hart 1979). It is very abundant at times and in certain places. *Caridina* may occur in large abundance in some macrophyte beds, but not in others (Hart 1979).

Table 5.6 Density per exposure rating (where 1 = quiet → 4 = most exposed) (Hart 1979)

Exposure rating	Density (gm.m^{-2})
1	6.4
2	0.3
3	2.3
4	2.9

Littoral densities (Hart 1979):

Mean density = 695.7 individuals m$^{-2.}$

Mean biomass = 2845.0 mg m^{-2} dry mass.

Caridina occurs everywhere along the margins of the lake except the barren sandy beaches. They are attracted to deposits of wrack (Hart 1979).

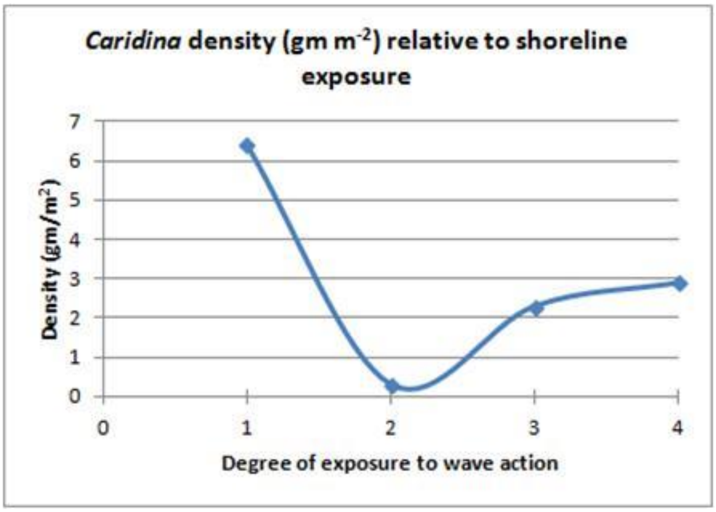


Figure 5.16 Abundance (density) relative to wave exposure

Habitat and microhabitat requirements (mainly for depth and substratum type)

Not inshore (excluding marginal vegetation), submerged macrophytes, sandy bottoms, silty bottoms, no depth constraints (Hart 1979). This is a species that is likely to be tolerant to change.

Additional relevant information

- Wide ranging opportunistic detritivore (Hart 1979). Phytoplankton is used extensively (Hart 1980).
- Caridina are fed on by *Clarias gariepinus* (Allanson 1979b). They are also preyed on by birds and other fish.
- This is a very important ecosystem component in Lake Sibaya that feeds on detritus and micro-algae.
- Abundance is affected by a rise in water (which floods vegetation and creates more habitat and shelter) and vice versa for a falling lake level.
- Abundance affected by area of lake bed. Total biomass reduced if bed size declines,
- Abundance affected by growth of submerged macrophytes (e.g. *Myriophyllum* (alien) and other plants. An increase in plants would result in an increase in *Caridina.*
- An important feature is the shoreline vegetation. This includes the presence and length of shoreline vegetation and of newly flooded vegetation.

5.11.2 Hymenosoma orbiculare

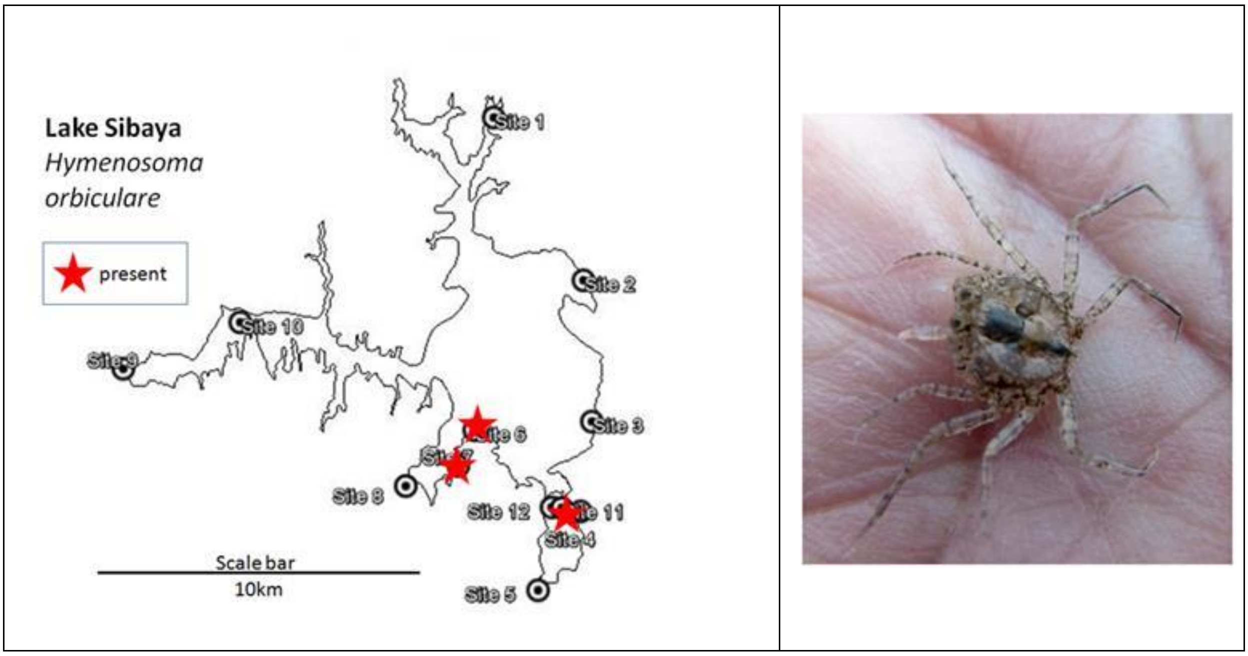


Figure 5.17 Distribution of *Hymenosoma orbiculare* in the lake and photograph

Species description

This crab is normally regarded as an estuarine species (Hart 1979). It occurs in shallow or deep water – hiding under the surface of the sand. It feeds on detritus, periphyton, benthic algae and on other benthic organisms.

Distribution and abundance (in particular depth-related limitations to spatial distribution)

It is a common/important species (Hart 1979)

Mean densities = 0.3 m^{-2}. (Hart 1979. refers to Forbes & Hill; Boltt 1969a).

Mean mass per animal = 48.0 mg (Hart 1979. refers to Forbes & Hill).

Mean biomass (dry) = 14.4. mg m^{-2}. (Hart 1979).

They are more numerous in winter (Hart 1979).

Densities on sandy bottoms = 0.7 m^{-2} and silty bottoms = absent. (Hart 1979. refers to Boltt 1969).

Table 5.7 Density per depth range Hart (1979)

Depth (m)	Density (number m^{-2})*	Dry mass (mg m^{-2})*
0-10	0.19	9.1
10-20	0.25	12.0
20-30	0.36	17.3
30-40	0.15	7.2
Average	0.23	10.9

(*These ignore seasonal differences, and differences between sediment type are ignored)

Habitat and microhabitat requirements (mainly for depth and substratum type)
Inshore (excluding marginal vegetation), submerged macrophytes and stems, sandy bottoms (Hart 1979). Not on silty bottoms (Hart 1979). No depth constraints (Hart 1979). It can be an important ecosystem component at times. It is preyed on by fish.

Anticipated sensitivities to change in water levels/salinities
Marine stock zoeae cannot survive in Sibaya (Hart 1979. refers to Forbes & Hill 1969). The Sibaya stock possibly relies on a raised ion content of Sibaya e.g. calcium enrichment of water, to cope with the low osmotic pressures (Hart 1979).

Additional relevant information
In the zooplankton the zoeae larvae of *Hymenosoma* are amongst the largest of the zooplankton forms – and occur in moderate densities (Hart 1980). *Hymenosoma* are fed on by *Clarias* (Allanson 1979b).

5.11.3 Potamonautes sidneyi

Potamonautes sidneyi : **River crab**	

Figure 5.18 Representative photograph of *Potamonautes sidneyi*

Species description: the river crab.

Distribution and abundance (in particular depth-related limitations to spatial distribution)
Littoral densities:
Mean density = 0.6 indiv m$^{-2.}$
Mean biomass = 285 mg m^{-2} (Hart 1979).

Habitat and microhabitat requirements (mainly for depth and substratum type)

Found to be common on the land-ward side of emergent vegetation. In places it burrows into the dry bank. Presumably burrows are deep enough to reach water.

Anticipated sensitivities to change in water levels/salinities

Likely to be a robust generalist species.

Additional relevant information

Fed on by juvenile crocs and birds (e.g. herons).

5.11.4 Tarebia granifera

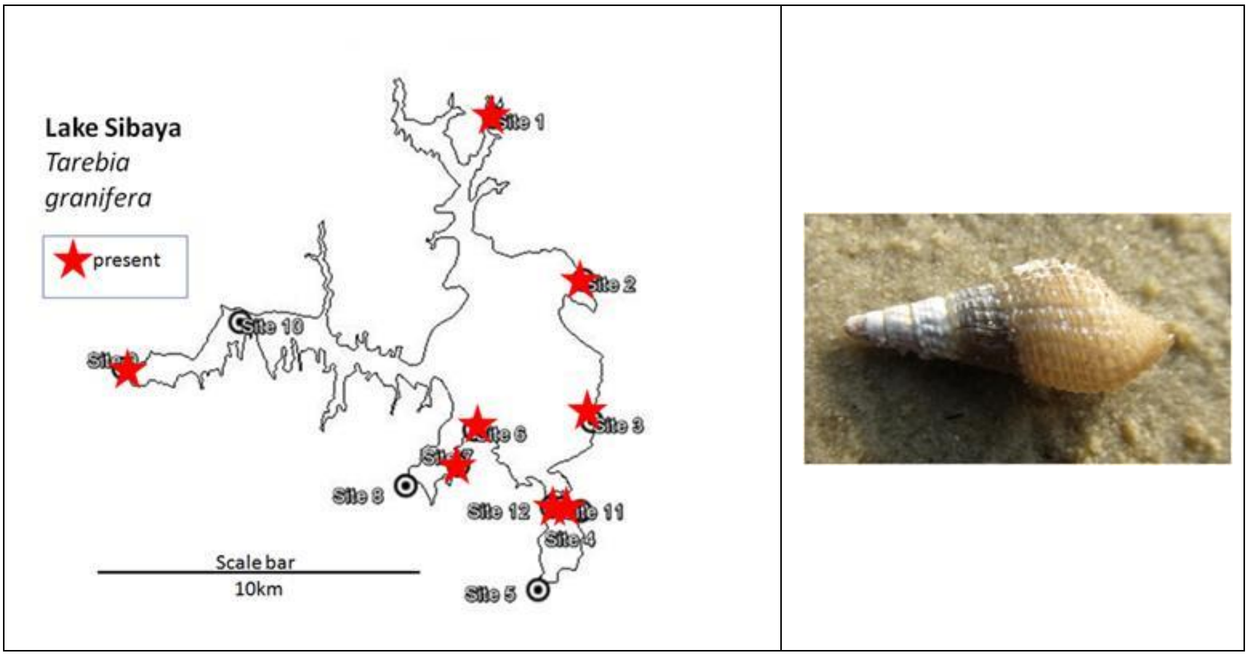


Figure 5.19 Distribution of *Tarebia granifera* in the Lake and photograph

Species description

It is invasive in South Africa; where the first record was at Mandini in 1999 (Appleton *et al.*2009). It is likely to have been in Lake Sibaya since about 2003. It is now widespread and extremely abundant throughout the photic zone of the system,

Distribution and abundance (in particular, depth-related limitations to spatial distribution)

This alien invasive snail is capable of maintaining densities of over 1000 individuals per m^{-2} at invaded sites (Miranda and Perissinotto 2014).

Lake Sibaya: *T. granifera*: Average abundance = 9602.08 individuals per m^{2}. Contribution = 99.44 % (Miranda & Perissinotto 2014).

Tarebia granifera dominated the benthic community in the relatively small shallow terrace, where shelter from wave action was provided by vegetation. It is unclear when *T. granifera* was introduced, but its invasion has spread at least along the entire eastern shallow shores of Lake Sibaya (Miranda & Perissinotto 2012).

Habitat and microhabitat requirements (mainly for depth and substratum type)

It feeds on detritus and micro-algae. Although it is regarded as a freshwater species, *T. granifera* is also adapted to brackish environments (Miranda & Perissinotto 2014). It has 'exceptional environmental tolerance' (Miranda & Perissinotto 2014).

Life histories

Populations are essentially composed of females which reach sexual maturity at a shell height between 6 and 8 mm (Miranda & Perissinotto 2014). *T. granifera* is parthenogenetic and ovoviviparous, giving birth to live juveniles and often reaching population densities of over 1000 individuals per m^{-2} (Miranda & Perissinotto 2012).

Additional relevant information

- Multivariate analyses seem to suggest that *T. granifera* may be causing homogenisation across the different coastal lakes of iSimangaliso (Miranda & Perissinotto 2014).
- Although *T. granifera* has the potential to have no significant feeding impact (Miranda *et al.* 2011a), it has often been reported in the literature as reducing the population densities of native molluscs (Miranda & Perissinotto 2014). *T. granifera* can dominate and thus significantly affect native assemblage composition (Miranda & Perissinotto 2014). Appleton *et al.*(2009) say that it will displace *Melanoides tuberculata*.
- Appleton *et al*. (2009) predicted that *T. granifera* is likely to alter the structure and diversity of benthic communities in the habitats it invades (Miranda & Perissinotto 2014).
- Following the invasion by *T. granifera*, the entire eastern shore of Lake Sibaya is dominated by this mollusc, as reflected by results from the three sites sampled in both the wet and dry seasons. Notably, *Melanoides tuberculata*, which had been recorded there in the past, is not currently found.(Miranda & Perissinotto 2014).
- Note: at the most exposed shorelines, *Melanoides* is still more abundant than *Tarebia* (Taylor, pers obs 2015).

5.11.5 Corbicula africana

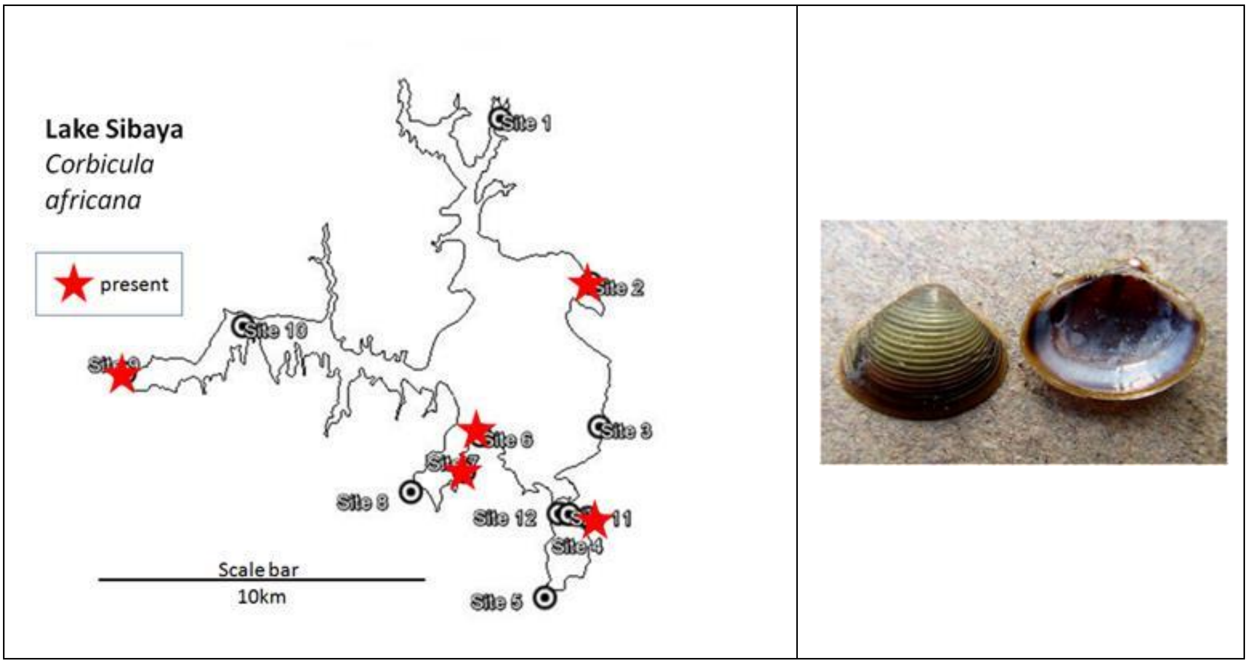


Figure 5.20 Distribution of *Corbicula africana* in the Lake and photograph

Species description: Freshwater species (Hart 1979).

Distribution and abundance (in particular depth-related limitations to spatial distribution

Common throughout the system, but note that Hart (1979) considered this species to be 'uncommon or rare'.

Lives both in littoral and submerged vegetation, and in sedimentary substrata (Appleton 1980).

July 2015 field trip – found throughout the system, except no shells were found washed up in the North Arm – but likely to occur there.

Habitat and microhabitat requirements (mainly for depth and substratum type)

Sandy bottoms (Hart 1979). Prefers sandy substrata. Lives embedded in the substratum – with only its siphons above the sand. Has no depth restrictions. Is widespread in the system.

No depth constraints (Hart 1979). *Corbicula africana* was recorded to 33 m. (Boltt 1969 in Appleton 1977).

Found from approx. 0.5 m in sheltered sand to 33 m in silt substrate in Lake Sibaya (Boltt 1969).(Appleton 1977). Food is filtered organic particles and small organisms.

Additional relevant information

Fed on by *Clarias* (Allanson 1979b).

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5.11.6 Melanoides tuberculatus

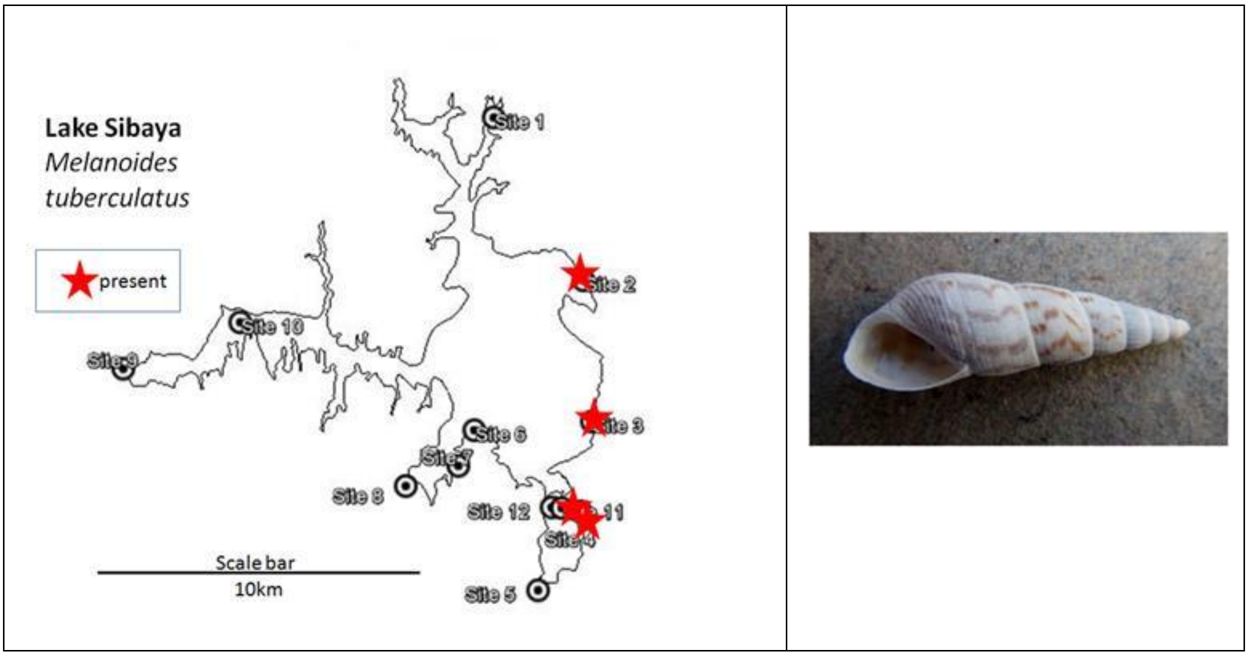

Figure 5.21 Distribution of *Melanoides tuberculatus* in the Lake and photograph

<u>Species description</u>: This is a freshwater species (Hart 1979).

<u>Distribution and abundance (in particular depth-related limitations to spatial distribution)</u>

Common/important species (Hart 1979).

Co-dominant with *Bellamya capillata* (Hart 1979).

Lives in both littoral and submerged vegetation and in sedimentary substrates (Appleton 1980).

Mean density = 32.2 m^{-2} (Boltt 1969 in Hart 1979).

% frequency = 0.4 (Hart 1979).

Mean mass per animal = 54.0 mg (Boltt 1969 in Hart 1979).

Calculated – mean mass = 1738.8 mg m^{-2}.

Densities:

Sandy bottom = 8.9 m^{-2} (Boltt 1969 in Hart 1979).
Silty bottom = 56 m^{-2} (Boltt 1969 in Hart 1979).

Table 5.8 From Hart (1979) giving densities per depth range

Depth (m)	Density (number m^{-2})*	Dry mass (mg m^{-2})*
0-10	8.5	459.0
10-20	0.15	8.1
20-30	2.9	156.6
30-40	22.2	1198.8
Average	6.3	339.8

(*These ignore seasonal differences, and differences between sediment type are ignored)

In Lake Sibaya Boltt (1969) has shown that *Bellamya capillata* and *Melanoides tuberculata* are amongst the most abundant invertebrates on sand and silt substrates in the main basin, being distributed from shallow terraces (0-2 m) to beyond the 24 m depth contour. (Appleton 1977).

Table 5.9 Biomass of snails per kilogram of weed at different depths (Appleton 1977)

Depth (m)	No snails/kg of weed (wet weight)
0.5	1.4
1	3
1.4	4.9
2.8	7.9
3.2	13.2
4.3	3.6
3.7	4
4.5	3.9
4.7	1.4
5	6.7

Habitat and microhabitat requirements (mainly for depth and substratum type)

Inshore (excluding marginal vegetation), submerged macrophytes and stems (Hart 1979).
Sandy bottoms, silty bottoms (Hart 1979).
No depth constraints (Hart 1979).
Found in a variety of habitats, from approx. 0,2 m in very shallow streams to 35 m in Lake Sibaya (Boltt 1969). (Appleton 1977).

Life histories

Reproduction = viviparous (Appleton 1980).

Additional relevant information

Fed on by Clarias (Allanson 1979b).
Appleton *et al.* (2009) says that it is displaced by the invasive alien snail *Tarebia granifera.*

5.11.7 Bulinus globosus

Figure 5.22 Line drawing of *Bulinus globosus*

<u>Species description</u>: A pulmonate snail with an average length of about 1 to 1.2 cm.

<u>Habitat and microhabitat requirements (mainly for depth and substratum type)</u>

Bulinus (Physopsis) globosus. - Found on marginal vegetation and down to about 2 m on *Schoenoplectus scirpioides* and submerged *Myriophyllum spicatum*, and to 0.3 m on sheltered sand in which it was noted to bury itself. (Appleton,1977).

<u>Distribution and abundance (in particular depth-related limitations to spatial distribution</u>

Table 5.10 Biomass of snails per kilogram of weed at different depths (Appleton 1977)

Depth (m)	No snails/kg of weed (wet weight)
0.5	1.8
1	1.6
1.4	2.3
2.8	0
3.2	0
4.3	0
3.7	0
4.5	0
4.7	0
5	0

An important result of the inundation of this grassland was its colonization by *Bulinus (Ph.) globosus*, the intermediate host of both *Schistosoma haematobium* (Bilharz), human urinary bilharzia, and *Schistosoma mattheei* Veglia & Le Roux, bovine bilharzia in the area (Appleton 1977). Previously this snail was known only from the marginal vegetation of all but the barren, oligotrophic shores of the lake. In May 1976 it not only seemed more common in the inundated areas than it had been in the 'old' marginal fringe, but was often the only mollusc found. It appears to be a 'pioneer' species (Appleton 1977).

Additional relevant information

Host for *Schistosoma haemotobium* (Appleton 1980)

5.11.8 Pulmonate snails – (*excluding* Bulinus globosus):

Freshwater pulmonate snails  *Bulinus natalensis*	 *Lymnaea natalensis(?)* and *Biomphalaria pfeifferi (?)*

Figure 5.23 Representative photograph of pulmonate snails

Note – *Bulinus globosus* is treated separately as there is sufficient knowledge for it, and also because it has social consequences as an intermediate host for urinary bilharzias.

Species description

The pulmonate freshwater snails are light-shelled. They lack an operculum. They are usually associated with submerged or emergent plants. The *Bulinus* and *Lymnaea* both have an average length of about 1 to 1.2 cm. The *Biomphalaria* is about half this size.

Bulinus natalensis – This genus has a 'sinistral' twist to the shell – all the other genera are 'dextral'

Lymnaea natalensis - typical snail shell

Biomphalaria pfeifferi – a 'rams-horn' shell

Habitat and microhabitat requirements (mainly for depth and substratum type)

During the July 2015 field trip some pulmonate snails including *Bulinus natalensis,* and *Biomphalaria pfeifferi* were recorded. These were exclusively in submerged or emergent vegetation beds. They were considered to be suitable indicator species for the lake as a guild.

These are all freshwater species present on all submerged macrophytes and stems (Hart 1979).

All pulmonates live in the littoral and submerged vegetation – none in the sedimentary substrata (Appleton 1980).

More pulmonates in sheltered than exposed weed beds (Appleton 1976 & Appleton 1977 in Hart 1979).

Anything that increases vegetation – will increase numbers of pulmonate snails (e.g. nutrient enrichment, more area within photic zone).

Distribution and abundance (in particular depth-related limitations to spatial distribution

Lymnaea natalensis is common/important (Hart 1979). Found amongst marginal vegetation and to 4.7 m on *M. spicatum* in Guguswana Bay (Lake Sibaya) (Appleton 1977).

Table 5.11 Biomass of snails (*Lymnaea*) per kilogram of weed at different depths (Appleton 1977)

Depth (m)	No snails/kg of weed (wet weight)
0.5	1.1
1	0.7
1.4	6.4
2.8	1.8
3.2	0
4.3	0
3.7	0.5
4.5	0.3
4.7	0
5	0

Bulinus natalensis occurred in both weed and sand to the limit of the submerged weed belt at approximately 7 m. (Boltt 1969 in Appleton 1977).

Bulinus natalensis = inshore, sandy bottom, 7 m (Hart 1979).

Mean density = 0.6 m^{-2} (Boltt 1969 in Hart 1979).

% frequency = 0.007 (Hart 1979).

Quantitative sampling in Empayeni pond (adjacent to Lake Sibaya) revealed that *B. natalensis* has only one generation per year, unlike other local planorbids which have three (Appleton 1974). *Bulinus natalensis* which takes six months to reach maturity is thus a slow-growing species, a feature which seems compatible with the suggestion that on morphological grounds it is adapted to lacustrine (i.e. stable) conditions. (Appleton 1977).

Table 5.12 Biomass of snails (*Bulinus*) per kilogram of weed at different depths (Appleton 1977)

Depth (m)	No snails/kg of weed (wet weight)
0.5	3.6
1	7.3
1.4	21
2.8	43.9
3.2	29.6
4.3	10.7
3.7	16
4.5	26.7
4.7	17.5
5	6

Biomphalaria pfeifferi is found on marginal vegetation to 4.5 m on *Myriophyllum spicatum* in Guguswana Bay (Lake Sibaya) and to 1.6 m on *S. litoralis* and firm sandy mud in Empayeni pond (Appleton 1977).

Table 5.13 Biomass of snails (*Biomphalaria*) per kilogram of weed at different depths (Appleton 1977)

Depth (m)	No snails/kg of weed (wet weight)
0.5	5
1	4
1.4	7.7
2.8	3.3
3.2	1.2
4.3	1.1
3.7	1.0
4.5	2.8
4.7	0
5	0

Anticipated sensitivities to change in water levels/salinities

All the freshwater pulmonate snails in Lake Sibaya have a maximum salinity tolerance of about 1 to 2 ppt (Appleton 1980).

Additional relevant information

Predators of the pulmonate snails include Lampyrid beetle larvae (*Luciola* sp) (Appleton 1980).

Biomphalaria pfeifferi is a host for *Schistosoma mansoni* (Appleton 1980). However, this form of bilharzias is not prevalent in the Lake Sibaya region.

5.11.9 Bellamya capillata

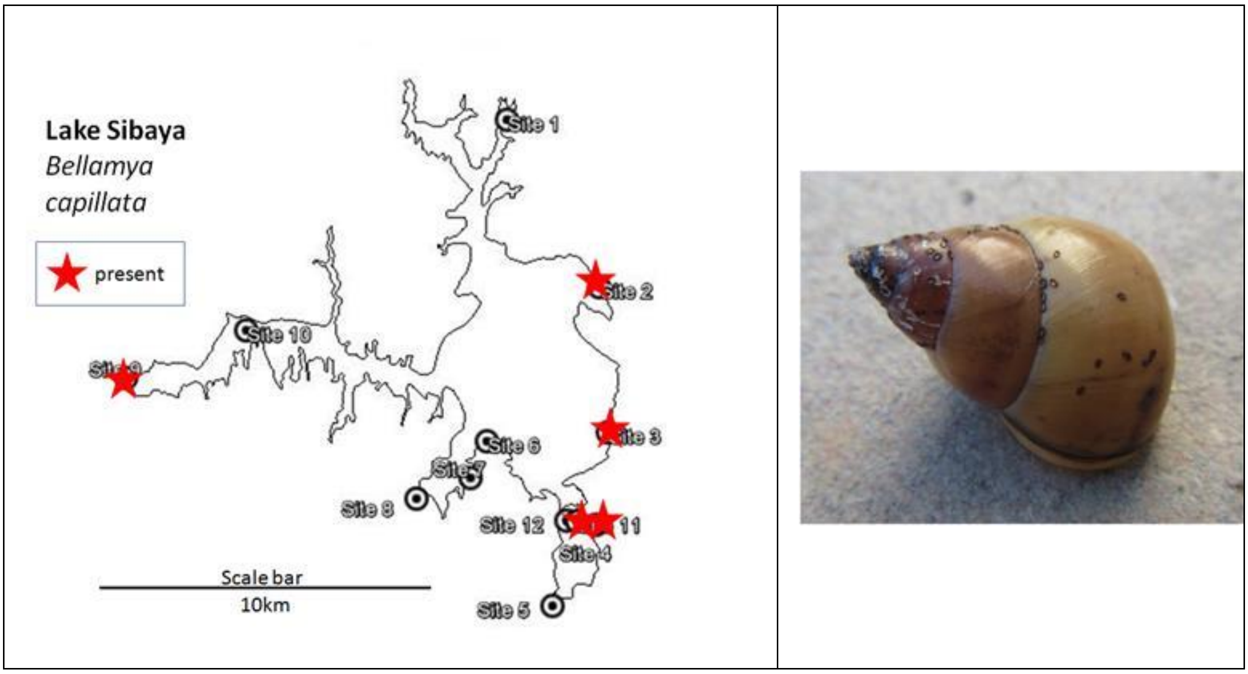

Figure 5.24 Distribution of *Bellamya capillata* in the Lake and photograph

<u>Species description</u>

Freshwater species (Hart 1979). Length about 2 to 3 cm. A tropical species with its southern limit in Lake Sibaya (Appleton 1977).

<u>Distribution and abundance (in particular depth-related limitations to spatial distribution)</u>

Common/important (Hart 1979).

Co-dominant with *Melanoides* (Hart 1979).

Mean density (Boltt 1969, Rudd unpubl. in Hart 1979) = 4.0 m^{-2}.

% frequency = 0.05.

Mean mass per animal (Rudd unpubl. in Hart 1979) =99.0 mg.

Mean biomass = 396.0 mg m^{-2} (dry) (Hart 1979).

It is less numerous in winter (Hart 1979).

Densities: (Boltt 1969 in Hart 1979).

Sandy 0.5 m^{-2}

Silty 7.4 m^{-2}

Table 5.14 Densities per depth range (Hart 1979)

Depth (m)	Density (number m^{-2})*	Dry mass (mg m^{-2})*
0-10	2.5	247.5
10-20	0.48	47.5
20-30	2.5	247.5
30-40	37.6	3722.4
Average	3.4	335.1

(*These ignore seasonal differences, and differences between sediment type are ignored)

In Lake Sibaya, Boltt (1969) has shown that *Bellamya capillata* and *Melanoides tuberculata* are amongst the most abundant invertebrates on sand and silt substrates in the main basin, being distributed from shallow terraces (0-2 m) to beyond the 24 m depth contour (Appleton 1977).

Habitat and microhabitat requirements (mainly for depth and substratum type)

Inshore (excluding marginal vegetation), submerged macrophytes and stems (Hart 1979).
Lives both in littoral and submerged vegetation, and in sedimentary substrates (Appleton 1980).
Sandy and silty bottoms (Hart 1979).
No comment is given on depth constraints (Hart 1979).
A common species found from approx. 0.4 m (Empayeni pond) to 30.4 m on hard sand covered with a 1-2 cm layer of soft detritus in Lake Sibaya (Bruton, unpubl. data). (Appleton 1977).

Life histories

All females. (Appleton 1980). Reproduction is parthenogenic (Appleton 1980).

Additional relevant information

- Fed on by Clarias (Allanson 1979b).
- Widespread within Lake Sibaya. Has a wide range of habitats and occurs at all depths. Regarded by Hart (1979) as ‘abundant’, yet we did not see enough evidence to support this assessment in our July 2015 field trip.
- This species was not chosen for use in the DRIFT model.

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6 FISH

6.1 Introduction

This section comprises the summary report for fish, and provides:

- An overview of the study area;
- A brief literature review;
- Description of the EWR sites;
- EcoClassification assessment of the lake's fishes, with supporting evidence;
- Description and results of a field survey conducted in July 2015;
- DRIFT indicators chosen, and reasons therefore, as well as linked indicators;
- Relationships between indicators and linked indicators (DRIFT Response Curves);
- Ecological Specifications (EcoSpecs) describing the Recommended Ecological Status with respect to fishes and suggested monitoring actions for these EcoSpecs;
- Fish catch per unit effort data from the field survey conducted in July 2015.

6.2 Description of the study area and introductory notes on the lake fish

Lake Sibaya is located in northern KwaZulu-Natal (KZN) at the Southern end of the Mozambique peneplain. It lies near just inland of the iSimangaliso Wetland Park, narrowly separated from the sea by coastal dunes north of Sodwana.

The system is an endorheic lake with seasonally connected swamps and shallow pans. It is characterised by clear, well-oxygenated waters supporting aquatic life, but with elevated chloride and calcium ions of marine origin and from fossil sources in tertiary sands. Geological marine (estuarine) connectivity is reflected in the fish and invertebrate fauna. The ionic balance (elevated sodium chloride (NaCl) and calcium) is likely to play an important direct role in the case of the estuarine invertebrate species and an indirect role (trophic) at least in the case of the fish species.

More detailed description of Lake Sibaya's fishes is provided in subsequent sections of this report, but some introductory information is provided here. Eighteen fish species are known to occur in the lake. These are mostly species typical of lowland freshwaters in KZN but several fishes more typically associated with estuarine waters also occur as relicts of the lake's estuarine past. The most important group of the system's fish in terms of abundance are cichlids, comprising several species but dominated by the Mozambique tilapia *Oreochromis mossambicus.* These fish are limited by food quality and to a lesser (and partially related) extent by habitat quantity and quality. The largest fish species and most important fish predator in the lake is the Sharptooth catfish (*Clarias gariepinus*). This fish is limited by food quantity and quality, its primary prey item being *Oreochromis mossambicus*.

6.3 Literature review

A good deal of research has been conducted and published on various aspects of the natural history of Lake Sibaya. There are excellent accounts of the ecology of the lake and biology of selected species of plants, invertebrates, fishes and other vertebrates in the system, based largely on research activities by the institute for Freshwater Studies at Rhodes University from 1965 to 1977. Information from these studies and the works published from them has formed the primary basis for identification of fish habitats and water quality criteria of importance to fishes in Sibaya for this study. This work is old but not outdated and it provides a good basis for use in the reserve determination study for the lake. Due to their age, some of the publications were difficult to source, but excellent syntheses exist in Allanson (1979a) and Bruton (1980).

The geological history of Lake Sibaya is an important determinant of its present day bathymetric, physico-chemical and biological characteristics. This system is a relict estuary that lost its free connection with the marine environment when sea level dropped during the Pleistocene glaciation (Hill 1969). Estuarine associated fauna have since persisted in the lake (Allanson *et al*. 1966). Raised chloride levels are likely an important determinant in the maintenance of the relict estuarine invertebrate fauna at least (Allanson and van Wyk 1969, Hart 1979), Calcium may also play a role. Forbes and Hill (1969) suggested that calcium enrichment was important in the allowing early life stage development of the estuarine crown crab *Hymenosoma projectum* in the lake.

This land-locked freshwater lake has also retained an estuarine component in its fish assemblage (Bruton, 1979a, 1980). Estuarine fishes include two pelagic open water species (a clupeid and an atherinid) and three benthic gobiids. Of these, the river goby *Glossogobius callidus* occurs widely in freshwaters independent of estuaries. The Sibaya goby *Silhouettea sibayi* and the burrowing goby *Croilia mossambica* have far stronger estuarine affinities and are not elsewhere found in land-locked freshwaters. Both are species of conservation significance, being rare and threatened in South Africa (Skelton 1993). *Silhouettea sibayi* is listed as Endangered by IUCN (very limited geographic range and extent and/or quality of habitat; Engelbrecht and Bills 2007) and *Croilia mossambica* is listed in the Least Concern category (Cambray and Tweedle 2007). Both of the estuarine associated pelagic species; the estuarine round-herring *Gilchristella aestuaria* and Cape silverside *Atherina breviceps*, are known to occur (and complete their lifecycles) in freshwater coastal lakes that are isolated from estuaries (and the sea) (Whitfield, 1998, Weerts *et al*. 2001). In KZN however, neither appear to persist ubiquitously in systems that become isolated from estuarine and marine connectivity and *Atherina breviceps* in particular occurs rarely (SP Weerts, pers obs.).

Water quality in Lake Sibaya is good. Despite the system's depth the full water column is well oxygenated during the cool months. In summer some reduction in oxygen tensions may occur in the deeper layers (Allanson, 1979b) but even then available data suggest that concentrations do not fall to levels that are limiting to aquatic biota in the lake. The lake is oligo-mesotrophic and characterised by clear water and stable pH (Allanson, 1979b, 1979c).

6.4 Field data collection and analysis

For the purposes of this study a short field trip was conducted to Lake Sibaya on 14 – 16 July 2015. Twelve sites (Figure 6.1) were sampled for fishes using a 30 m x 1.7 m x 15 mm bar mesh seine net fitted with a 5 mm bar mesh purse. Replicate hauls were taken at all sites with the exception of Site 8 where the bathymetry and vegetation prevented a good second haul being taken. Fish were identified and measured to the nearest 10 mm Standard Length in the field and returned live to the water with little exception. A few specimens that could not be positively identified were preserved in 10% buffered formalin and returned to the laboratory for taxonomic verification and measurement. The assistance of Mr Molefi Mazibuko of the Department of Water and Sanitation is acknowledged, with gratitude.

Water samples were collected for laboratory analyses and *in situ* measurements made with a calibrated YSI multi-parameter probe. The results of these analyses and measurements are described in the Water Quality specialist report compiled by Dr Susan Taljaard for the purposes of this EWR study and are not repeated here.

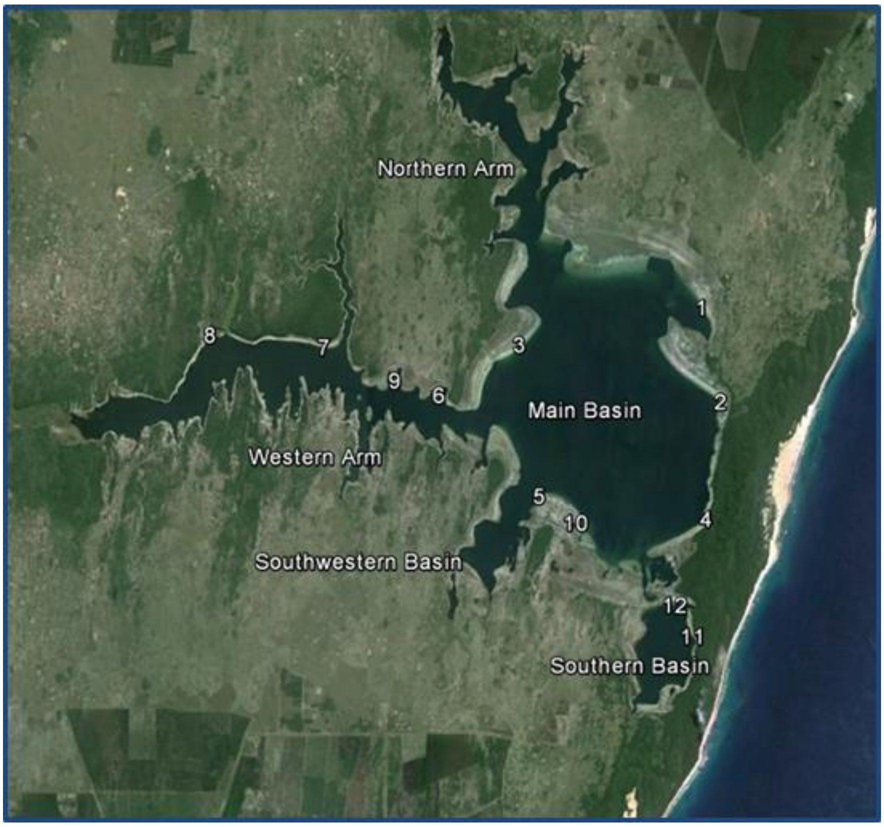


Figure 6.1 **The five main EWR zones of Lake Sibaya and sites sampled during a field survey conducted in July 2015**

6.5 Description of the EWR areas

For the purposes of EWR assessment, the lake was divided onto five main zones (Figure 1.1). These zones follow those of Hill (1979):

- **Main Basin**: The largest region comprising approximately 50% of the lake area and containing the deepest water;
- **Southern Basin**: A smaller basin (~ 5% of the lake area) which is currently (winter 2015) separated from the rest of the lake because of low lake water levels caused by prolonged drought and increased surface and ground water abstraction;
- **Southwestern Basin**: A smaller basin (~ 5% of the lake) to the southwest of the Main Basin and which remains well linked with the rest of the lake, even under current low water level conditions;
- **Western Arm**: A large (~20% lake area) dendritic arm with the settlement of Mseleni at its western extremity;
- **Northern Arm**: A smaller (~ 10% lake area) arm at the northern end of the Main Basin.

6.6 EcoClassification of Lake Sibaya as represented by fish

6.6.1 Reference Condition

In its recent natural state, unimpacted by modern anthropogenic activities, Lake Sibaya was an oligo-mesotrophic, endorheic lake with seasonally connected swamps and shallow pans. It was a large, deep system with a convoluted shoreline and naturally fluctuating water level. It was characterised by clear, well-oxygenated waters with naturally elevated chloride and calcium concentrations. Fish species occurring in the lake were presumed to be similar to those that presently occur. Several estuarine associated fish species that may have occurred in the lake's geological past (after it lost its free connection with the marine environment during the Pleistocene glaciation) would not have survived the transition to a permanent isolated freshwater state. These extinctions from the lake were natural and resulted from loss of marine connectivity and life history requirements of the species in question not being met in the isolated freshwater lake.

Connectivity with surrounding pans and wetlands was a feature of Lake Sibaya in its Reference Condition, and indeed the lake was part of a wider linked wetland system that included the Kosi estuarine lakes to the north and several permanent and temporary wetlands in-between. During sustained high water levels, these linkages may have provided the opportunity for recruitment into the lake of fish species that have not been reported there (e.g. anguillid eels) (Bruton 1979a).

Water levels in the lake were closely correlated with groundwater, and fluctuated widely. There was no particular "normal" state and the system was naturally dynamic (Hill 1979). Fluctuating water levels played an important role in the ecology of the system. At high lake levels large areas of shallow shelf were used by biota and fish to gain access to flooded marginal habitats and allocthonous carbon inputs (from flooded terrestrial vegetation). With decreasing water levels shallow areas naturally became increasingly wave washed and during drought periods fish habitat quality in shelf areas was poor. Under conditions of progressive lake level drop and at low water levels, shallow water aquatic vegetation died back, representing further loss of fish habitat and food. During summer days water temperatures in these very shallow areas increased to levels too high for adults of several species, which may have affected their metabolic rates, and displacing them from the shallower parts. These shallow areas were also impacted by wave turbulence and this affected detritus and microphytobenthic food resources on the shallow terrace. These food resources, especially diatoms, were important for *Oreochromis mossambicus*, the most abundantly occurring fish in the lake.

Thus water level in the lake was naturally dynamic, and natural fluctuations in water level have affected the fishes in the lake. The rate of change in water level has also varied widely but changes of > 1 m are likely to have occurred over several years (Hill 1979).

6.6.2 Present State and threats to fish

In comparison to many other water resources in South Africa, Lake Sibaya remains in a relatively natural state. Large-scale industrial and urban development in the catchment has not occurred. That said, rural development, agriculture and forestry have all increased over the last century and continue to do so at a rapid rate. The system and its biological assemblages are increasingly used by a local population, which has grown markedly, as well as an increasing tourist population.

Fish have historically formed part of the diet of the Thonga people on the Maputaland coast (Pooley 1980). Several traditional fishing methods have been used in Lake Sibaya. Fishing still occurs, has probably increased, and includes the use of modern equipment. However gill netting does not seem to be widely practised in the lake, and certainly not to the degree that has become problematic in other Maputaland systems. This is probably mainly linked to the naturally low fish yield of Lake Sibaya. Indeed, while tribes local to the lake have traditionally harvested a wide variety of fish species from the system, most of their fishing returns are obtained in the nearby Indian Ocean (Bruton 1979b). Changes in the fishes of Lake Sibaya that are attributable to increased fishing pressure are therefore likely to be of minor consequence. They are probably reflected in slightly reduced fish abundance and community composition impacts due to a disproportionate impact on the primary target fish species.

Water quality impacts on the lake, from developments and land uses outlined above, are likely to have occurred. These are described in the Water Quality specialist report compiled by Dr Susan Taljaard for the purposes of this EWR study and are not repeated here. In summary, these water quality impacts are small and highly localised. Overall they are not expected to have had any marked impact on the fishes of the lake, which are generally comprised of species tolerant of some degree of water quality impairment. Ionic ratios are likely to be important for at least some of the estuarine associated species that persist in the system, but these have remained suitably high in chloride and calcium to support all life stages of the extant fishes (and invertebrates) in the lake.

Water quantity, specifically reflected in lake water level, is likely to be the most influential aspect of the lake’s present day characteristics that have impacted the fish community. The natural hydrology of Lake Sibaya is impacted by abstraction of surface water and ground water, and rainfall and runoff. Water is drawn from the lake to meet the requirements of several settlements and growing towns, such as Mbaswana and Mseleni. Additionally, forestry has increased dramatically in the area and in recent years there has been a shift to from Pine to Eucalyptus plantations, which is presumed to have increased drawn-down of the water table. In a system that is so heavily reliant on ground water inputs, groundwater lowering has exacerbated the (natural) impacts of the current drought conditions prevailing in the area, and has resulted in lake water levels that have dropped faster, and to levels lower than ever previously recorded.

Water level effects on fishes have included both direct and indirect impacts. Shallow water habitats are the most important areas for most species and these have been impacted most by water level drops. Shallow areas (<3 m) form a relatively narrow periphery around an otherwise deep waterbody. An important feature of the system is its terrace habitats (*sensu* Bruton 1979a). Shallow water area, marginal shoreline length and terrace habitats have all been significantly reduced in recent years of prolonged drought and increased (surface and ground) water abstraction.

The shallow terraces around the periphery of Lake Sibaya are particularly important as feeding areas for *Oreochromis mossambicus*. Diatoms and detritus are the main food items of this species. Both occur in highest abundance on terrace substrate between 0.5 m and 1.5 m deep (Bowen 1978). Digestible protein in benthic floc in the lake is negatively related to water depth (Bowen 1976), so highest food quality also occurs in this relatively narrow depth zone. Higher temperature tolerance of juvenile cichlids allows them to access the shallow areas and their food resources during the day, but can preclude adults (Bruton 1979b, and references therein). Reduced depth has the propensity to result in both higher temperatures on the terrace, and increased wind-generated wave action churning up bottom sediments and the feeding grounds of *O. mossambicus*.

Other species are also affected by low lake water levels. Impacts are discussed further in later sections of this report, but include loss of spawning area for *Clarias gariepinus* and loss of aquatic vegetation habitat for barbs, topminnows, cichlids and *C. gariepinus*. Climbing perch *Ctenopoma multispine* is particularly affected by low lake levels and associated loss of connectivity with adjacent swamps, pans and wetlands.. This species (together with *Clarias theodorae* and *C. gariepinus* to a lesser extent) has strong affinities for coastal lakes with associated swamps and wetlands. Its breeding strategy includes overland migration to shallow peripheral wetlands to spawn. These can occur as mass migrations (Skelton 1993). In Lake Sibaya groups of over 50 individuals have been noted to congregate in a spawning run and migrate overland to adjacent swampy areas and streams. Mating and egg deposition take place in temporary water bodies after rains (Bruton 1979a). Loss of these peripheral wetlands, and loss of connectivity to them during rainy periods, therefore results in population losses of this species.

Undoubtedly, the current low lake water level in Lake Sibaya has affected the fish community. As indicated above, fluctuating lake water level is a natural attribute of the lake, and these types of impacts have occurred in the past. The rate, magnitude and persistence of the current water level drop, however, is believed to result from human influences in the catchment , and is expected to cause deviations in the lake’s fish fauna away from its Reference Condition. At present, changes in the fish community and abundance is buffered to a large extent, by the tolerance of most of the lake's fishes to environmental perturbations and their longevity. As yet, it is unlikely that species have been lost from the system because of the recent drops in water level. However, reproductive success of some species is likely to have been affected, and should the low lake water levels persist, or decrease over a further prolonged period, more significant reductions in ecological state of the ichthyofauna is expected to occur, with possible species extinctions from the system. Given the isolated nature of the lake, natural recovery of some species is highly unlikely, especially those with estuarine associations.

6.6.3 Ecostatus of the fish fauna of Lake Sibaya by EWR site

Ecological categories applied to fishes in Lake Sibaya (Present and Recommended) are tabulated below (Table 6.1).

Table 6.1 Ecostatus and Recommended Ecological Category of fish assemblages in Lake Sibaya

EWR Area	% EC	EC	REC	Of significance/reason for REC
Main Basin	85	B	A	Prolonged water level drop has reduced habitat for key elements of the fish assemblage. Habitat loss is most pronounced in the Main Basin. All species remain in the basin and although abundances are reduced they are expected to recover should water level recover. The lake borders a World Heritage Site and has a unique fish fauna assemblage. This includes relict estuarine species, species with a high degree of endemism and species of conservation significance in KZN, SA and regionally.
Northern Arm	90	A	A	Prolonged water level drop has reduced habitat for key elements of the fish assemblage. Habitat loss is less pronounced in the Northern Arm compared to the lake's basins. Of importance in the Northern Arm is connectivity to swamps and wetlands which are important as breeding areas where climbing perch migrate during the wet season. These fish species remain in the system and are expected to recover should water level recover. The lake borders a World Heritage Site and has a unique fish fauna assemblage. This includes relict estuarine species, species with a high degree of endemism and species of conservation significance in KZN, SA and regionally.
Western Arm	95	A	A	Prolonged water level drop has reduced habitat for key elements of the fish assemblage. Habitat loss is less pronounced in the Western Arm compared to the lake's basins. Of importance in the Western Arm is connectivity to swamps and wetlands which are important as breeding areas where climbing perch migrate during the wet season. Fish species remain in the system and are expected to recover should water level recover. The lake borders a World Heritage Site with a unique fish fauna assemblage. This includes relict estuarine species, species with a high degree of endemism and species of conservation significance in KZN, SA and regionally.
Southwestern Basin	90	A	A	Prolonged water level drop has reduced habitat for key elements of the fish assemblage. Habitat loss is less

EWR Area	% EC	EC	REC	Of significance/reason for REC
				pronounced in this basin compared to the lake's other basins. Of importance in the Southwestern Basin is its connectivity to wetlands which are important as breeding areas where climbing perch migrate during the wet season. Fish species remaining in the system are expected to recover should water level recover. The lake borders a World Heritage Site with unique fish fauna assemblage. This includes relict estuarine species, species with a high degree of endemism and species of conservation significance in KZN, SA and regionally.
Southern Basin	85	B	A	Prolonged water level drop has reduced habitat availability for key elements of the fish assemblage. Habitat loss is fairly pronounced in this basin, and of more concern is that it has separated from the rest of the lake in recent months. Continued loss of water and water level reduction (which is accelerated compared to the rest of the lake under separation) renders this basin more susceptible to water quality impacts. Fish species remaining in the system are expected to recover should water level recover. The lake borders a World Heritage Site with a unique fish fauna assemblage. This includes relict estuarine species, species with a high degree of endemism and species of conservation significance in KZN, SA and regionally.

6.7 Results

A list of fish species sampled during the July 2015 field survey (described in section 6.4) is provided in Table 6.2, together with species not collected but previously reported from the lake. Site-specific catch per unit effort data are provided in section 6.12.

Ten of the eighteen confirmed fish species from Lake Sibaya were sampled in July 2015. Nine of these were from seine net catches from shoreline habitats (open terrace and shallow submerged aquatic vegetation). *Aplocheilichthys katangae* was sampled by Dr Petro Vos when sweep netting marginal vegetation in the Western Arm. All other species listed are likely still to occur in the system, and their absence from survey records in July 2015 is a result of limited sampling effort and sampling bias (e.g. fishing gear being restricted to 30 m seine net deployed in very shallow habitats during winter daytime only).

No alien species were sampled in July 2015. *Micropterus salmoides* (Large-mouth bass) was introduced into Lake Sibaya in 1935 but has not subsequently been reported in scientific surveys of the system (Bruton 1979a). Given the considerable effort spent by researchers sampling and studying the system in the 1970's it is likely (and fortunate) that this early introduction was unsuccessful. Should *M. salmoides* (or any of the other bass species or similar alien fish predator) have established in the lake it would have had significant impacts on populations of indigenous fish. Any further attempt at alien fish introductions should be firmly discouraged.

Given the fish survey limitations conducted for this study, it is difficult to extrapolate and compare the results with earlier more detailed surveys across different seasons. Catches were markedly lower than might have been expected from similar habitats in other KZN freshwater or estuarine systems, but this may have been a result of sampling conditions, exacerbated by the very clear waters of the Lake. Surprisingly, in spite of the wealth of information available on species biologies in Lake Sibaya, little information could be sourced on fish abundances that could be directly compared with seine net catches from July 2015. Of note (and some concern) was the relative abundance of *Atherina breviceps* compared with *Gilchristella aestuaria* in the lake. Typically, in KZN systems *G. aestuaria* is by far the more dominant of these two species (and indeed most often occurs exclusively). This warrants further investigation in Lake Sibaya.

Table 6.2 List of fish species occurring in Lake Sibaya (and their conservation statuses). * = endemic to Southern Africa, ** = endemic to KwaZulu-Natal)

Family	**Species**	**Common name**	**Conservation status (IUCN 2015)**	**Sampled 07-2015**
Atherinidae	*Atherina breviceps**	Cape silverside	Not assessed	✓
Clupeidae	*Gilchristella aestuaria**	Estuarine round herring	Least Concern	✓
Gobiidae	*Croilia mossambica**	Burrowing goby	Least Concern	
	*Silhouettea sibayi**	Sibaya goby	Endangered	✓
	*Glossogobius callidus**	River goby	Least Concern	✓
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	Least Concern	✓
	Pseudocrenilabrus philander	Southern mouthbrooder	Not assessed	✓
	Tilapia rendalli	Reb breasted tilapia	Least Concern	✓
	Tilapia sparrmanii	Banded tilapia	Least Concern	✓
Clariidae	*Clarias gariepinus*	Sharptooth catfish	Least Concern	
	Clarias theodorae	Snake catfish	Least Concern	
Cyprinidae	*Barbus paludinosus*	Straightfin barb	Least Concern	
	Barbus viviparus	Bowstripe barb	Least Concern	✓
	Labeo molybdinus	Leaden labeo	Least Concern	
Anabanitdae	*Ctenopoma multispine*	Manyspined climbing perch	Least Concern	
Mormyridae	*Marcusenius macrolepidotus*	Bulldog	Least Concern	
Cypriniodontidae	*Aplocheilichthys katangae*	Striped topminnow	Least Concern	✓
	*Aplocheilichthys myaposae***	Natal topminnow	Least Concern	

6.8 Identification of indicators

6.8.1 Indicator list for fish

Fish species were selected as indicators based on various aspects of their life histories, feeding biology and habitat requirements. Selection of indicator species was made difficult by the fact that the freshwater fishes of coastal KZN are typified by species which are often ubiquitous and r to perturbations in environmental characteristics. There are, however, as indicated in the literature review above, excellent accounts of the ecology of Lake Sibaya and biologies of selected species of fishes in the system. Information from these studies and the works published from them formed the basis for identification of fish habitats and water quality criteria of importance to fishes in Sibaya.

On the basis of this, and the known bathymetry of Lake Sibaya, shallow water fish habitats are considered most sensitive to lake water level fluctuations, and particularly to low lake water level, and sudden or prolonged decreases in lake water level. because they occur on the shallow, flat shelf around the lake periphery. Small water level drops result in disproportionate habitat area losses on this gradually sloping shallow shelf. Most affected are marginal habitats (shallow pools and flooded vegetated fringes around the lake perimeter) and terrace habitats (on the near-flat littoral shelves and which are either vegetated or can be open sand substrates). Shallow slopes (2 – 5 m water depth) are less affect by water level fluctuation, while deep areas and open water are the least potentially impacted fish habitat types.

Shallow habitats, in addition to being the most sensitive to water level changes, are also the most important for fishes in Lake Sibaya. Very shallow water (< 0.5 m) is important for small fry, which can withstand the temperature extremes during warm summer days to access the flooded perimeter water as a predation refuge and assimilate allochthonous carbon inputs in the form of flooded terrestrial vegetation (and associated invertebrate prey items). Waters between 0.5 and 1.5 m are where the highest abundances of diatoms occur, which are very important for juvenile *O. mossambicus* (Bowen 1976, Bruton 1979a). Digestible protein in benthic floc is negatively related to depth in waters (Bowen 1976). Higher temperature tolerance of juvenile cichlids allows them to access this food resource during the day, but can preclude adults (Bruton 1979a, and references therein). In Lake Sibaya the shallow water area is limited, and adult *O. mossambicus* are restricted to feeding on poor quality food resources in deeper waters due to their temperature preferences (Bruton 1979a) and the need to avoid (avian) predators in the clear water system.

Thus, the terrace flats are used as breeding, nursery and feeding habitats by a variety of species. Water temperature, wave impacts, and vegetation coverage and inundation dictate the habitat quality for fishes on these flats, and these environmental parameters are all impacted by water depth. Wave impacts on the substrate and aquatic vegetation are most severe in very shallow waters, for example. With receding lake water level, an increasing proportion of the terrace flats are exposed to wave wash, which can breakup vegetation beds and disturb cichlid feeding and nesting area, particularly those of *Oreochromis mossambicus*. Similarly, the use of shallow littoral areas by *Clarias gariepinus* is influenced by low lake water levels. This species has a relatively high dependency on shallow water habitats for foraging and breeding in the lake.

Based on the above points, *Oreochromis mossambicus* and *Clarias gariepinus* were selected as fish indicators. The choice of these two fish as indicator species may appearcounter-intuitive at face value. They are both widespread species, occurring in a wide variety of water bodies in KZN, and are hardy and tolerant of wide ranges in water quality. They are nevertheless keystone species in Lake Sibaya, and have atypical life histories in the system that have adapted to the lake bathymetric and water quality peculiarities.

The multispined climbing perch *Ctenopoma multispine* was also included as an indicator based on its strong dependence on lake water levels for breeding migration. Several other fish indicators were developed and used in the assessment for reasons which included being required by other disciplines (i.e. linked indicators). These included species that are important in the trophic dynamic system of the lake. Barbs and topminnows, cichlids, gobies and pelagic fishes for example are important as prey items to different components of the avifauna.

A list of fish species and guilds used as indicators in the EWR assessments is provided in Table 6.3.

Table 6.3 Fish indicators and reasons for their selection

Indicator	**Reasons for selection as indicator**
Mozambique tilapia *O. mossambicus*	Breeds in shallow waters 0.5 – 2.5 m (nests, wave and temperature effects). Juveniles strongly dependent on depths of 0.5 – 1.5 m as feeding areas (related to diatoms abundance/detritus protein values/temperature tolerance).
Sharptooth catfish *C. gariepinus*	Breeds in shallow terrace and marginal habitats and uses these habitats as nursery areas. Forages (group hunting) for prey in shallow waters. Temperature avoidance at low lake levels impacts use of terrace for feeding, hunting. Prey item for crocodiles.
Multispined climbing perch *Ctenopoma multispine*	Strong reliance on linked swamps and wetlands. Migrates overland during rain to reach associated pans for breeding.
Barbs and topminnows Cyprinidae, Cypriniodontidae	Strong association with peripheral vegetation beds (submerged vegetation < 5 m and emergent vegetation. Prey items for birds.
Pelagic species *G aestuaria and* *A. breviceps*	Representatives of pelagic food web. Both species are estuarine relicts and an important component of the lake that will not recover from localised extinction. Prey items for birds.
Other cichlids *P. philander, T. rendalli,*	Strong association with peripheral vegetation beds (submerged vegetation < 5 m and emergent vegetation. Make frequent use of terrace habitats.

Indicator	**Reasons for selection as indicator**
T. sparrmanii	Prey item for birds.
Gobies *C. mossambica, S. sibayi, G. callidus*	Include conservation significant species. Includes species that are estuarine relicts and an important component of the lake that is unlikely to recover from localised extinction. Prey items for birds.
Number of species	An important overall indicator of fish assemblage health in the lake.
Fishery biomass	An indication of the importance of lake fish in the diets of local people.

6.8.2 Linked indicators

Linked indicators for fish indicators are listed, with explanation, in Table 6.4 below.

Table 6.4 Linked indicators and motivation

Indicator	**Linked indicator**	**Motivation**
Mozambique tilapia *O. mossambicus*	Submerged, rooted vegetation	*O. mossambicus* has an affinity for vegetated habitats, which serves as a predation refuge, especially in clear waters (such as those in Lake Sibaya). These habitats are also preferred habitats for prey items (insects, shrimps etc.) for *O. mossambicus*, although these are probably secondary in importance as a food resource compared with phytobenthos (benthic diatoms in particular) and detritus in Lake Sibaya.
	Emergent macrophytes	
	Area 1.5 - 2 m	Different shallow waters are important for different reasons to different life stages of *O. mossambicus* in Lake Sibaya. Shallow water habitats (< 2 m) include the main breeding areas for the species where territorial males compete for area to build nests (Bruton 1979a). Slightly deeper areas are preferred to the very shallow wave washed terrace areas (Bruton and Allanson 1974).
	Area 1 - 1.5 m	Waters between 0.5 and 1.5 m have the highest abundance of diatoms in Lake Sibaya (Bowen 1978). These diatoms are very important in the diet of juvenile *O. mossambicus* (Bowen 1978, Bruton 1979a). Digestible protein in benthic floc is negatively related to depth in waters (Bowen 1976). Higher temperature tolerance of juvenile cichlids allows them to access this food resource during the day, but can preclude adults (Bruton 1979a, and references therein). In Lake Sibaya the shallow water area is limited, and adult *O. mossambicus* are restricted to feeding on poor quality food resources in deeper waters due to their temperature preferences (Bruton 1979a) and the need to avoid (avian) predators in the clear water system.
	Area 0.5 - 1 m	
	Area 0 - 0.5 m	Very shallow waters (< 0.5 m) are important for small fry, which can withstand the temperature extremes during warm summer days to access the flooded perimeter water as a predation refuge and access allochthonous carbon inputs (flooded terrestrial vegetation and associated invertebrate prey items).
Sharptooth catfish *C. gariepinus*	Mozambique tilapia *Oreochromis mossambicus*	*C. gariepinus* prey on a wide variety of food items and will adapt their feeding strategies according to prey abundance. However, in Lake Sibaya Mozambique tilapia is an important component of the diet of *C. gariepinus* and comprise over 60% (by dry weight) of the species prey (Bruton 1979a). The abundance of *C. gariepinus* in Lake Sibaya is expected to follow trends in *O. mossambicus* abundance.

Indicator	**Linked indicator**	**Motivation**
	Submerged, rooted vegetation	*C. gariepinus* occurs in a broad range of habitats, but has a preference for submerged aquatic vegetation, especially in early life stages (Skelton 1993). In clear water systems such as Lake Sibaya even adults show a strong affinity for vegetated areas as predation refugia.
	Area 1 - 1.5 m	Fish are an important component of the diet of *C. gariepinus*. *Oreochromis mossambicus,* especially, comprises a significant proportion of biomass eaten, and large catfish feed almost exclusively on this tilapia (Bruton 1979a and references therein). Social hunting is probably an important part of the fishes feeding strategy in Lake Sibaya. It has been observed to occur in the lake in shallow terrace waters at night (Bruton 1979a). Small cichlds (mainly *O. mossambicus*) are targeted and are herded into shallow waters where they are more susceptible to being caught. Shallow waters are also important spawning areas for *C. gariepinus*.
	Area 0.5 - 1 m	
	Area 0 - 0.5 m	Fish are an important component of the diet of *C. gariepinus*. *Oreochromis mossambicus* especially comprises a significant proportion of biomass eaten, and large catfish feed almost exclusively on this tilapia (Bruton 1979a and references therein). Social hunting is probably an important part of the fishes feeding strategy in Lake Sibaya. It has been observed to occur in the lake in shallow terrace waters at night (Bruton 1979a). Small cichlds (mainly *O. mossambicus*) are targeted and are herded into shallow waters where they are more susceptible to being caught. Shallow waters (< 0.5 m) are also important spawning areas for *C. gariepinus*. Generally, flooded marginal areas are preferred for mating and egg deposition (Skelton 1993). In Lake Sibaya spawning has been noted to generally take place in areas < 0.3 m depth (Bruton 1979a).
Multispined climbing perch *Ctenopoma multispine*	Swamp forest	*C. multispine* has a very restricted distribution in South Africa, occurring on the coastal plain of norther KZN. It has strong affinities for coastal lake systems with associated swamps and wetlands. Its breeding strategy includes overland migration to shallow peripheral wetlands to spawn. These can occur as mass migrations (Skelton 1993). In Lake Sibaya groups of over 50 individuals congregate in a spawning run and migrate overland to adjacent swampy areas and streams. Mating and egg deposition take place in temporary waters after rains (Bruton 1979a). Shallow swamp areas are therefore important for the species. Wetlands, temporary pans, and seasonal connectivity to these areas during rain events (even as wetted area) are therefore important for the species.
	Wetlands and pan connectivity	
Barbs and topminnows Cyprinidae, Cypriniodontidae	Submerged, rooted vegetation	*Aplocheilichthys* spp. (topminnows) and *Barbus* spp. (barbs) in Lake Sibaya all prefer vegetated habitats (Skelton 1993) which are used as predation refugia spawning areas, nurseries, and feeding habitats. In Lake Sibaya they occur in shallow as well as deep marginal habitats (Bruton 1979a).
	Emergent macrophytes	
Pelagic species *G aestuaria* and *A. breviceps*	Area	Two species of pelagic fishes occur, both with estuarine affinities; *Gilchristella aestuaria* (estuarine round herring) and *Atherina breviceps* (Cape silverside). These species are both zooplanktivores and are therefore indirectly dependant on phytoplankton biomass and productivity for their trophic base. They have different breeding strategies. *A. breviceps* has large glutinous eggs which attach to aquatic plants and other structure, while *G. aestuaria* has free floating eggs (Whitfield 1990). In general however, both species have a common and strong

Indicator	Linked indicator	Motivation
		dependency on open water areas, where they spend their entire life-cycle.
Other cichlids *P. philander, T. rendalli, T. sparrmanii*	Submerged, rooted vegetation	All cichlids in Lake Sibaya have an affinity for vegetated habitats, which serves as a predation refuge, especially in the system's clear waters. These habitats are also preferred habitats for prey items (insects, shrimps etc.) of many of the species and provide food directly for herbivorous fishes (most notably *Tilapia rendalli*).
	Emergent macrophytes	
	Area 2 - 5 m	Different shallow waters are important for different reasons to different life stages of the cichlid species in Lake Sibaya. Different species defend different spawning territories in the lake. Those of *O mossambicus* are in shallow waters while *T. sparrmannii* and *P. philander* occupy sequentially deeper zones (Bruton 1979a).
	Area 1.5 - 2 m	All species nevertheless typically prefer shallower water, where food resources are richest. Prey items included diatoms, insects, small epiphytic crustaceans and juvenile fishes (Bruton 1979a and references therein). Many, if not most of these prey species occur predominantly in the lake's shallow parts (< 2 m deep).
Gobies *C. mossambica, S. sibayi, G. callidus*	Area	Three species of goby occur in Lake Sibaya. These are *C. mossambica* (burrowing goby), *S. sibayi* (Sibaya goby) and *G. callidus* (river goby). The former two species have estuarine affinities, but complete their life cycles in the lake. They have wide habitat niches and are all feeders on benthic invertebrates. As such their broadest dependency is on water area.
Number of species	Area	There are 18 species in Lake Sibaya (Bruton 1979a). All have different requirements of habitats, water quality and water level for their continued existence in the system. Most are nevertheless robust and will persist in the lake even under relatively extreme conditions. The most sensitive and vulnerable species are those with dependencies on aquatic vegetation, and lake associated swamps and wetlands. Water area will also be limiting at extreme lake water levels.
	Submerged, rooted vegetation	
	Emergent macrophytes	
	Swamp forest	
	Wetlands and pan connectivity	
Fishery biomass	Mozambique tilapia *O. mossambicus*	Caught and eaten by local people (Bruton 1979b)
	Sharptooth catfish *C. gariepinus*	
	Multispined climbing perch *Ctenopoma multispine*	
	Barbs and topminnows Cyprinidae, Cypriniodontidae	
	Pelagic species *G aestuaria* and *A. breviceps*	
	Other cichlids *P. philander,* *T. rendalli,* *T. sparrmanii*	
	Gobies *C. mossambica,* *S. sibayi,*	

Indicator	Linked indicator	Motivation
	G. callidus	

6.9 Lake zone weightings

For the purposes of integrating the five EWR zones assessments into an assessment of the whole lake, weightings were applied to each of the EWR zones. These were indicator specific and the rationales for each are given below (Table 6.5):

Table 6.5 Species specific lake component weighting motivations

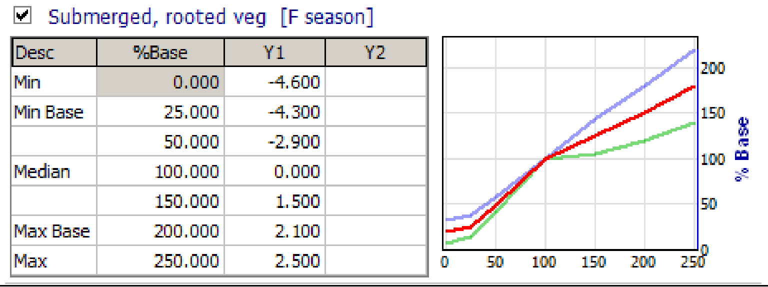
Indicator	Weighting and motivation
Mozambique tilapia *O. mossambicus*	Adult Mozambican tilapia occur in depths up to 18 m in Lake Sibaya (Bruton 1979a). The species however, has a depth preference for shallower areas. Area of water from 0 – 10 m was chosen as a weighting proxy for this species.
Sharptooth catfish *C. gariepinus*	Sharptooth catfish occur over all depths in Lake Sibaya, from the shallow lake edges to the depths of the profundal zone (Bruton 1979a). The species does however have a depth preference for shallower water and feed as well as breeding occurs in shallow zones. Area of water 0 – 30 m was chosen as a weighting proxy for this species.
Multispined climbing perch *Ctenopoma multispine*	Climbing perch have a strong preference for shallow water areas. They occur in marginal waters < 1.5 m in Lake Sibaya (Bruton 1979a). The Northern and Western Arms of the lake are the most important areas for this fish, having closest proximity to swamps and wetlands migrated into during the breeding season. Lake water area 0 - 1.5 m was chosen as a weighting proxy for this species. For the Northern and Western Arms these areas were multiplied by 3 to weight their relative importance.
Barbs and topminnows Cyprinidae, Cypriniodontidae	These small fishes all occur in shallow marginal waters (Bruton 1979a). Lake water area 0 – 5 m was chosen as a weighting proxy for this group of fishes.
Pelagic species G aestuaria and A. breviceps	These comprise estuarine round herring and Cape silverside. They occur across the full lake but are generally restricted to surface waters < 5 m in depth (Bruton 1979a). Surface area at -5 m was chosen as a weighting proxy for this group of fishes.
Other cichlids P. philander, T. rendalli, T. sparrmanii	This group comprises three cichlid species (not including *O. mossambicus*) with different reported maximum depth ranges in Lake Sibaya. They generally prefer shallower waters (albeit slightly deeper than *O. mossambicus*, Bruton 1979a). Lake water area 0 – 20 m was chosen as a weighting proxy for this group of fishes.
Gobies C. mossambica, S. sibayi, G. callidus	This group comprises three small fishes with different reported maximum depth ranges in Lake Sibaya. Lake water area 0 - 25 m was chosen as a weighting proxy for this group of fishes.
Number of species	Species most susceptible to being lost from the system are shallow water species. Lake water area 0 – 10 m was chosen as a weighting proxy for this indicator.
Fishery biomass	Fishes are caught in the entire lake, but areas in closest proximity to settlement are most fishes. These are the Western and Northern Arms of the lake. The Main Basin is subject to strong wind and wave action, and is probably least fished. The Square Root transformed “proximity rating” was

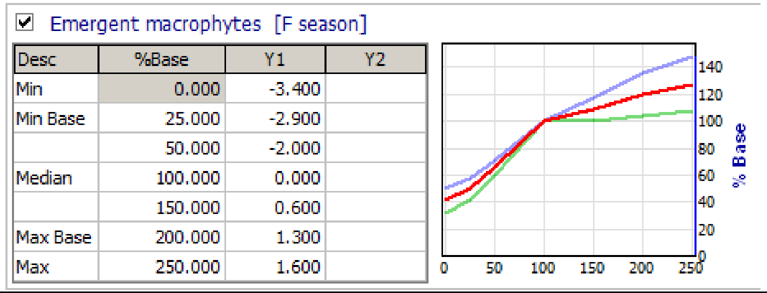
	used as a proxy for weighting lakes according to their contribution to fish biomass to the diets of local people.

6.10 Motivations for Response Curves

Indicators listed above, and associated linked indicators, formed the basis for populating the DRIFT model. Response curves were developed for appropriate indicators in each of the EWR regions. Examples of each indicator and linked indicator response curves are provided below.

6.10.1 Mozambique tilapia *O. mossambicus*

<table>
<tr><td colspan="2">Mozambique tilapia <i>O. mossambicus</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Submerged, rooted veg [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-4.600</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.300</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.900</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.100</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.500</td><td></td></tr>
</table>

</td><td><i>O. mossambicus</i> has an affinity for vegetated habitats, which serves as a predation refuge, especially in clear waters (such as those in Lake Sibaya). These habitats are also preferred habitats for prey items (insects, shrimps etc.) for <i>O. mossambicus</i>, although these are probably secondary in importance as a food resource compared with phytobenthos (benthic diatoms in particular) and detritus in Lake Sibaya.</td><td>High</td></tr>
<tr><td>

☑ Emergent macrophytes [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.400</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.900</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.600</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.300</td><td></td></tr>
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</table>

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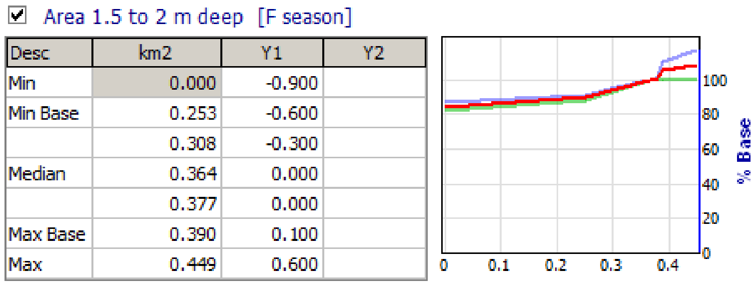
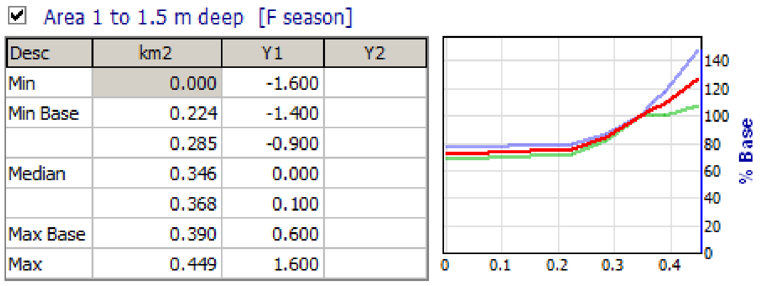
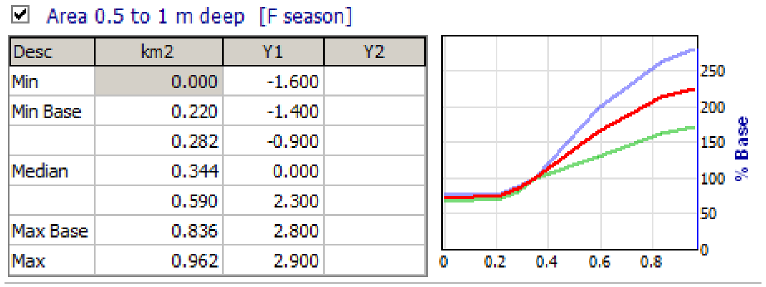
</table>

<table>
<tr><th colspan="2">Mozambique tilapia <i>O. mossambicus</i></th><th></th></tr>
<tr><th>Linked indicator response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ Area 1.5 to 2 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.900</td><td></td></tr>
<tr><td>Min Base</td><td>0.253</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>0.308</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>0.364</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.377</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>0.390</td><td>0.100</td><td></td></tr>
<tr><td>Max</td><td>0.449</td><td>0.600</td><td></td></tr>
</table>
</td>
<td>Different shallow waters are important for different reasons at different life stages of <i>O. mossambicus</i> in Lake Sibaya. Shallow water habitats (< 2 m) include the main breeding areas for the species where territorial males compete for area to build nests (Bruton 1979a). Slightly deeper areas are preferred to the very shallow wave washed terrace areas (Bruton and Allanson 1974).</td>
<td>Moderate</td></tr>
<tr><td>
☑ Area 1 to 1.5 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.224</td><td>-1.400</td><td></td></tr>
<tr><td></td><td>0.285</td><td>-0.900</td><td></td></tr>
<tr><td>Median</td><td>0.346</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.368</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>0.390</td><td>0.600</td><td></td></tr>
<tr><td>Max</td><td>0.449</td><td>1.600</td><td></td></tr>
</table>
</td>
<td>Waters between 0.5 and 1.5 m are where the highest abundances of diatoms occur in Lake Sibaya (Bowen 1978). These diatoms are very important in the diet of juvenile <i>O. mossambicus</i> (Bowen 1978, Bruton 1979a). Digestible protein in benthic floc is negatively related to depth in waters (Bowen 1976). Higher temperature tolerance of juvenile cichlids allows them to access this food resource during the day, but can preclude adults (Bruton 1979a, and references therein). In Lake Sibaya shallow water area is limited, and adult <i>O. mossambicus</i> are restricted to feeding on poor quality food resources in deeper waters due to their temperature preferences (Bruton 1979a) and the need to avoid (avian) predators in the clear water system.</td>
<td>High</td></tr>
<tr><td>
☑ Area 0.5 to 1 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.600</td><td></td></tr>
<tr><td>Min Base</td><td>0.220</td><td>-1.400</td><td></td></tr>
<tr><td></td><td>0.282</td><td>-0.900</td><td></td></tr>
<tr><td>Median</td><td>0.344</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.590</td><td>2.300</td><td></td></tr>
<tr><td>Max Base</td><td>0.836</td><td>2.800</td><td></td></tr>
<tr><td>Max</td><td>0.962</td><td>2.900</td><td></td></tr>
</table>
</td>
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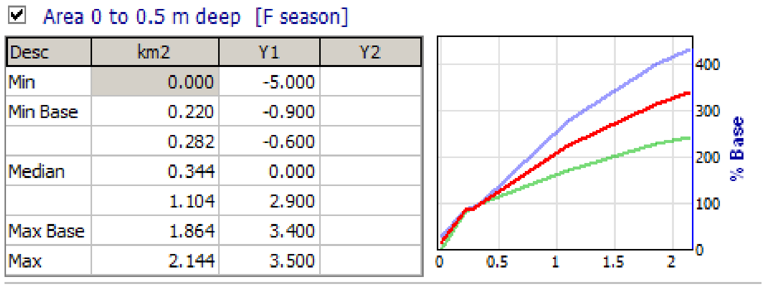
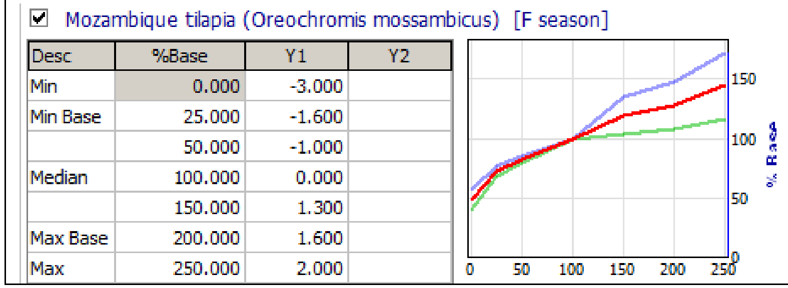
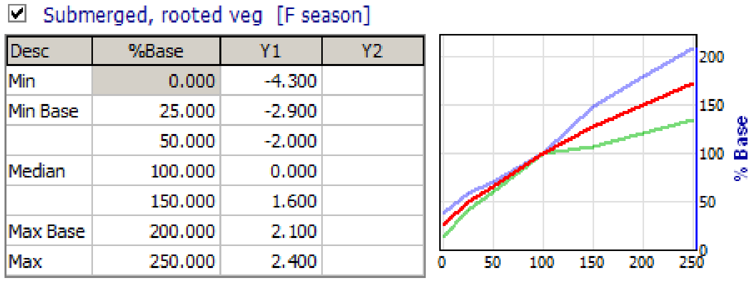
<td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Mozambique tilapia <i>O. mossambicus</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area 0 to 0.5 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.220</td><td>-0.900</td><td></td></tr>
<tr><td></td><td>0.282</td><td>-0.600</td><td></td></tr>
<tr><td>Median</td><td>0.344</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.104</td><td>2.900</td><td></td></tr>
<tr><td>Max Base</td><td>1.864</td><td>3.400</td><td></td></tr>
<tr><td>Max</td><td>2.144</td><td>3.500</td><td></td></tr>
</table>
</td><td>Very shallow waters (< 0.5 m) are important for small fry, which can withstand the temperature extremes during warm summer days to access the flooded perimeter water as a predation refuge and access allochthonous carbon inputs (flooded terrestrial vegetation and associated invertebrate prey items).</td><td>Moderate</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

6.10.2 Sharptooth catfish *C. gariepinus*

<table>
<tr><td colspan="2">Sharptooth catfish <i>C. gariepinus</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Mozambique tilapia (Oreochromis mossambicus) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.600</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.600</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.000</td><td></td></tr>
</table>
</td><td><i>C. gariepinus</i> prey on a wide variety of food items and will adapt their feeding strategies according to prey abundance. However, in Lake Sibaya Mozambique tilapia are an important component of the diet of <i>C. gariepinus</i> and comprise over 60% (by dry weight) of the species prey (Bruton 1979a). The abundance of <i>C gariepinus</i> in Lake Sibaya can therefore be expected to follow trends in <i>O. mossambicus</i> abundance.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Sharptooth catfish <i>C. gariepinus</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


☑ Submerged, rooted veg [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-4.300</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.900</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
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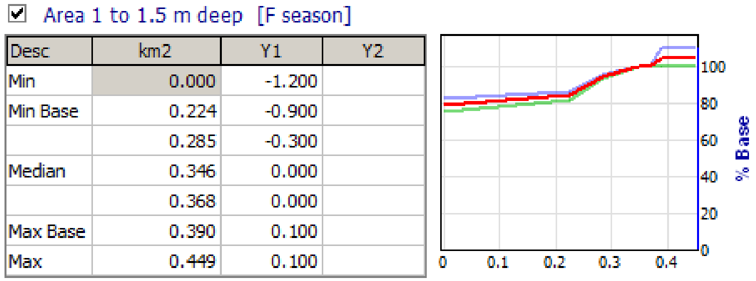
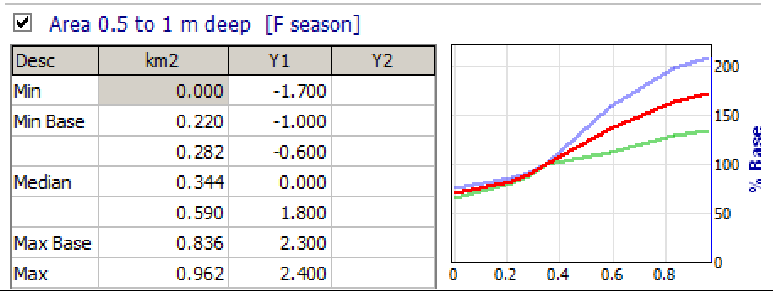
<tr><td>Max</td><td>250.000</td><td>2.400</td><td></td></tr>
</table>

</td><td><i>C. gariepinus</i> occurs in a broad range of habitats, but has a preference for submerged aquatic vegetation, especially in early life stages (Skelton 1993). In clear water systems such as Lake Sibaya even adults show a strong affinity for vegetated areas as predation refugia.</td><td>High</td></tr>
<tr><td>


☑ Area 1 to 1.5 m deep [F season]

<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.200</td><td></td></tr>
<tr><td>Min Base</td><td>0.224</td><td>-0.900</td><td></td></tr>
<tr><td></td><td>0.285</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>0.346</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.368</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>0.390</td><td>0.100</td><td></td></tr>
<tr><td>Max</td><td>0.449</td><td>0.100</td><td></td></tr>
</table>

</td><td>Fish are an important component of the diet of <i>C. gariepinus</i>. <i>Oreochromis mossambicus</i> especially comprises a significant proportion of biomass eaten, and large catfish feed almost exclusively on this tilapia (Bruton 1979a and references therein). Social hunting is probably an important part of the fishes feeding strategy in Lake Sibaya. It has been observed to occur in the lake in shallow terrace waters at night (Bruton 1979a). Small cichlids (mainly <i>O mossambicus</i>) are targeted and are herded into shallow waters where they are more susceptible to being caught. Shallow waters are also important spawning areas for <i>C. gariepinus</i>.</td><td>Moderate</td></tr>
<tr><td>


☑ Area 0.5 to 1 m deep [F season]

<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.700</td><td></td></tr>
<tr><td>Min Base</td><td>0.220</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>0.282</td><td>-0.600</td><td></td></tr>
<tr><td>Median</td><td>0.344</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.590</td><td>1.800</td><td></td></tr>
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<tr><td>Max</td><td>0.962</td><td>2.400</td><td></td></tr>
</table>

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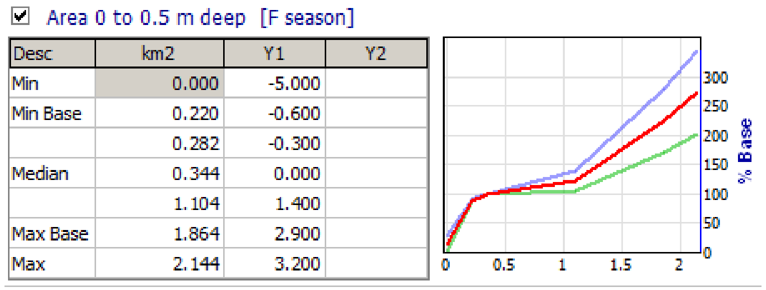
</table>

<table>
<tr><td colspan="2">Sharptooth catfish <i>C. gariepinus</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


☑ Area 0 to 0.5 m deep [F season]

<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.220</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>0.282</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>0.344</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.104</td><td>1.400</td><td></td></tr>
<tr><td>Max Base</td><td>1.864</td><td>2.900</td><td></td></tr>
<tr><td>Max</td><td>2.144</td><td>3.200</td><td></td></tr>
</table>

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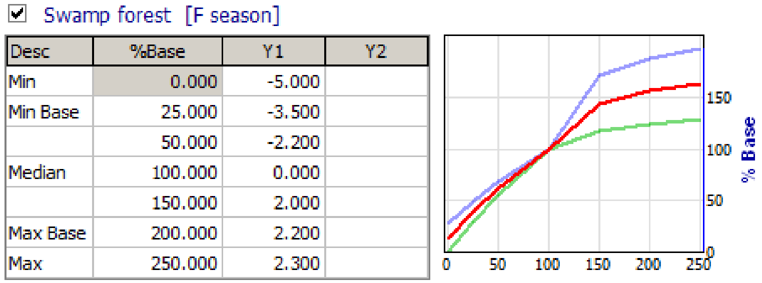
</table>

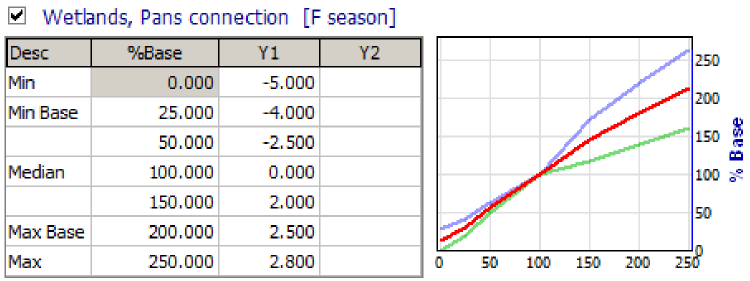
6.10.3 Multispined climbing perch *Ctenopoma multispine*

<table>
<tr><td colspan="2">Multispined climbing perch <i>Ctenopoma multispine</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


☑ Swamp forest [F season]

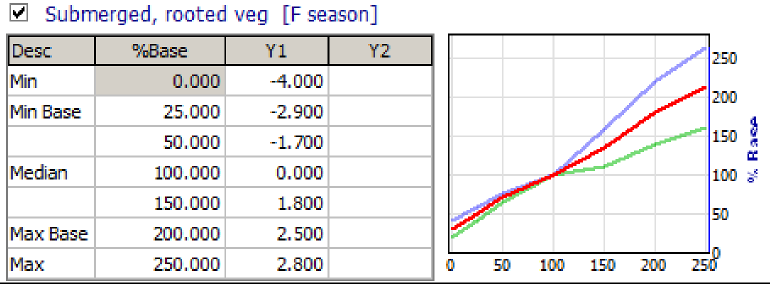
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-3.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.300</td><td></td></tr>
</table>

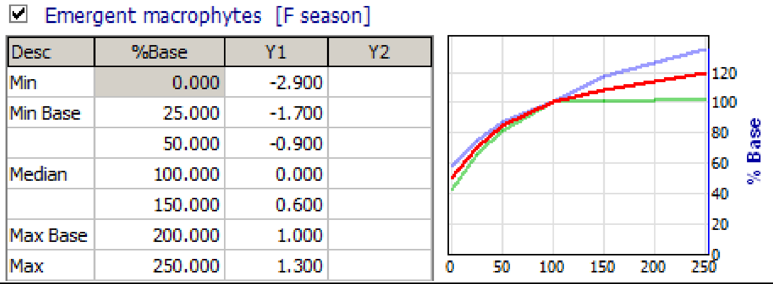
</td><td><i>C. multispine</i> has strong affinities for coastal lake systems with associated swamps and wetlands. Its breeding strategy includes overland migration to shallow peripheral wetlands to spawn. These can occur as mass migrations (Skelton 1993). In Lake Sibaya groups of over 50 individuals congregate in a spawning run and migrate overland to adjacent swampy areas and streams. Mating and egg deposition take place in temporary waters after rains (Bruton 1979a). Shallow swamp areas are therefore important for the species.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Multispined climbing perch Ctenopoma multispine</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Wetlands, Pans connection [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.800</td><td></td></tr>
</table>

</td><td>C. multispine has strong affinities for coastal lake systems with associated swamps and wetlands. Its breeding strategy includes overland migration to shallow peripheral wetlands to spawn. These can occur as mass migrations (Skelton 1993). In Lake Sibaya groups of over 50 individuals congregate in a spawning run and migrate overland to adjacent swampy areas and streams. Mating and egg deposition take place in temporary waters after rains (Bruton 1979a). Wetlands, temporary pans, and seasonal connectivity to these areas during rain events (even as wetted area) are therefore important for the species.</td><td>High</td></tr>
</table>

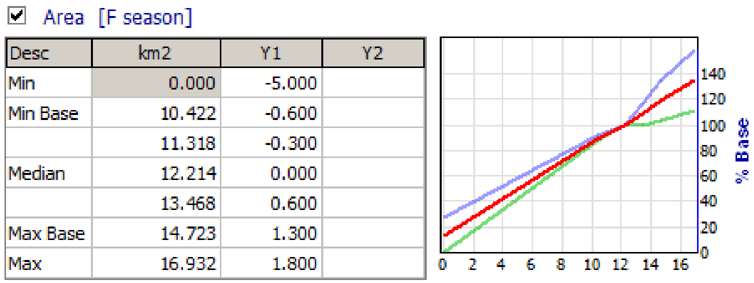
6.10.4 Barbs and topminnows Cyprinidae, Cypriniodontidae

<table>
<tr><td colspan="2">Barbs and topminnows Cyprinidae, Cypriniodontidae</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Submerged, rooted veg [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-4.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.900</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.700</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.800</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.800</td><td></td></tr>
</table>

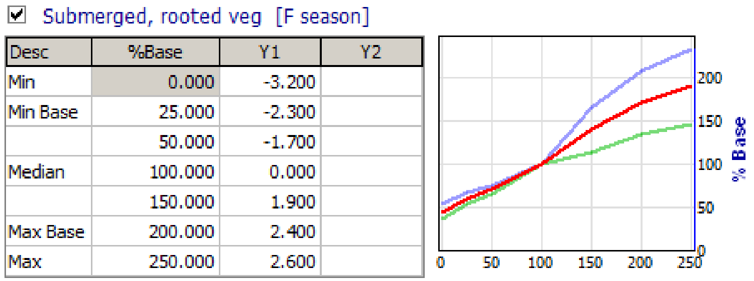
</td><td>Aplocheilichthys spp. (topminnows) and Barbus spp. (barbs) in Lake Sibaya all prefer vegetated habitats (Skelton 1993) which are used as predation refugia spawning areas, nurseries, and feeding habitats. In Lake Sibaya they occur in shallow as well as deep marginal habitats (Bruton 1979a).</td><td>High</td></tr>
<tr><td>

☑ Emergent macrophytes [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.900</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.700</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.900</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.600</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.300</td><td></td></tr>
</table>

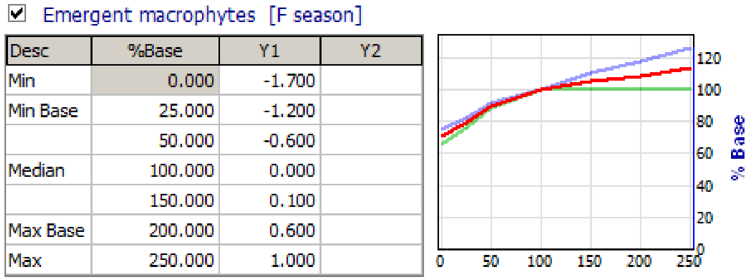
</td><td>Aplocheilichthys spp. (topminnows) and Barbus spp. (barbs) in Lake Sibaya all prefer vegetated habitats (Skelton 1993) which are used as predation refugia spawning areas, nurseries, and feeding habitats. In Lake Sibaya they occur in shallow as well as deep marginal habitats (Bruton 1979a).</td><td>High</td></tr>
</table>

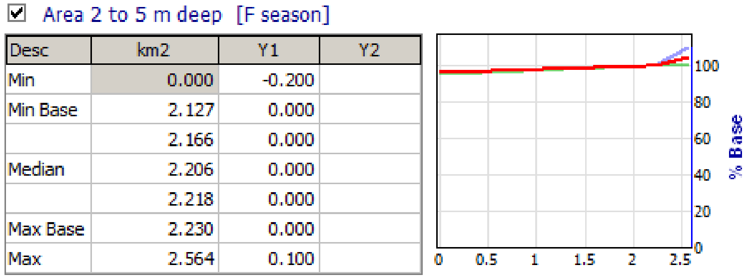
6.10.5 Pelagic species *C. aestuaria* and *A. breviceps*

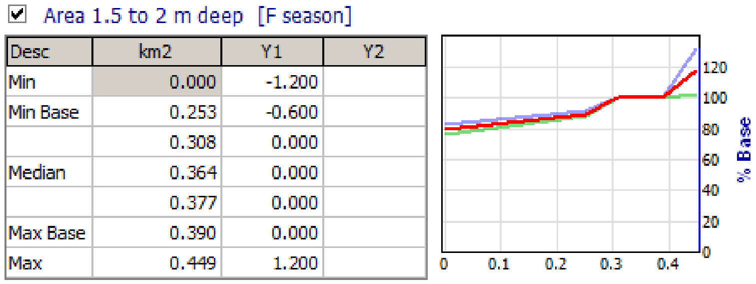
<table>
<tr><td colspan="2">Pelagic species <i>G aestuaria</i> and <i>A. breviceps</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>10.422</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>11.318</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>12.214</td><td>0.000</td><td></td></tr>
<tr><td></td><td>13.468</td><td>0.600</td><td></td></tr>
<tr><td>Max Base</td><td>14.723</td><td>1.300</td><td></td></tr>
<tr><td>Max</td><td>16.932</td><td>1.800</td><td></td></tr>
</table>
</td><td>These species are both zooplanktivores and are therefore indirectly dependent on phytoplankton biomass and productivity for their trophic base. They have different breeding strategies. <i>A. breviceps</i> has large glutinous eggs which attach to aquatic plants and other structure, while <i>G. aestuaria</i> has free floating eggs (Whitfield 1990). In general however, both species have a common and strong dependency on open water areas, where they spend their entire life cycle. Water surface area is a good proxy for habitat availability for these fishes.</td><td>High</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

6.10.6 Other chichlids *P.philander, T. rendalli, T sparrmanii*

<table>
<tr><td colspan="2">Other cichlids <i>P. philander, T. rendalli, T. sparrmanii</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Submerged, rooted veg [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.200</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.300</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.700</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.900</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.400</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.600</td><td></td></tr>
</table>
</td><td>All cichlids in Lake Sibaya have an affinity for vegetated habitats, which serves as a predation refuge, especially in the system's clear waters. These habitats are also preferred habitats for prey items (insects, shrimps etc.) of many of the species and provide food directly for herbivorous fishes (most notably <i>Tilapia rendalli</i>).</td><td>High</td></tr>
</table>

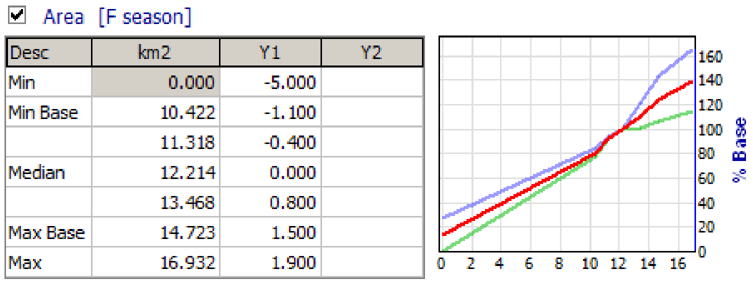
<table>
<tr><td colspan="2">Other cichlids <i>P. philander, T. rendalli, T. sparrmanii</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Emergent macrophytes [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.700</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.200</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.600</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.600</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.000</td><td></td></tr>
</table>

</td><td>All cichlids in Lake Sibaya have an affinity for vegetated habitats, which serves as a predation refuge, especially in the system's clear waters. These habitats are also preferred habitats for prey items (insects, shrimps etc.) of many of the species and provide food directly for herbivorous fishes (most notably <i>T. rendalli</i>).</td><td>Moderate</td></tr>
<tr><td>

☑ Area 2 to 5 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.200</td><td></td></tr>
<tr><td>Min Base</td><td>2.127</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.166</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>2.206</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.218</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>2.230</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>2.564</td><td>0.100</td><td></td></tr>
</table>

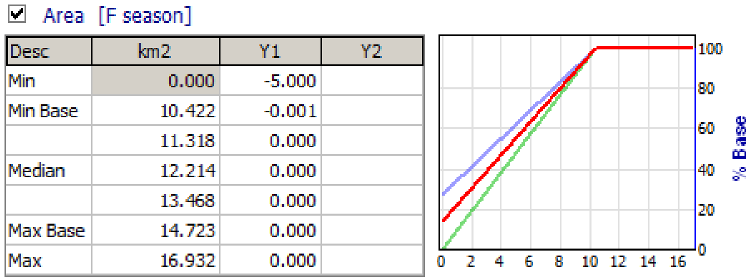
</td><td>Different shallow waters are important for different reasons to different life stages of the cichlid species in Lake Sibaya. Different species defend different spawning territories in the lake. Those of <i>O. mossambicus</i> occur in shallow waters, while <i>T. sparrmannii</i> and <i>P. philander</i> occupy sequentially deeper zones (Bruton 1979a).</td><td>Moderate</td></tr>
<tr><td>

☑ Area 1.5 to 2 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.200</td><td></td></tr>
<tr><td>Min Base</td><td>0.253</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>0.308</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.364</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.377</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>0.390</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>0.449</td><td>1.200</td><td></td></tr>
</table>

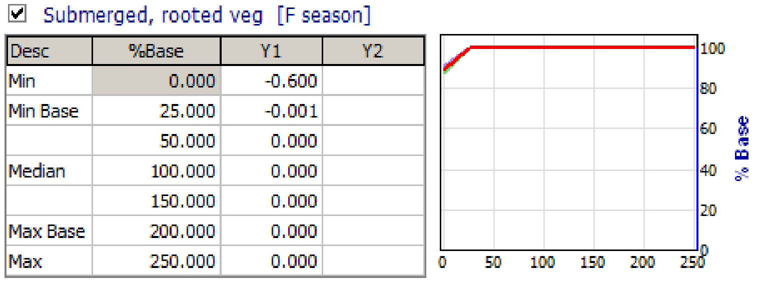
</td><td>All species nevertheless typically prefer shallower water, where food resources are richest. Prey items included diatoms, insects, small epiphytic crustaceans and juvenile fishes (Bruton 1979a and references therein). Many, if not most of these prey species occur predominantly in the lake's shallow parts (< 2 m deep).</td><td>Moderate</td></tr>
</table>

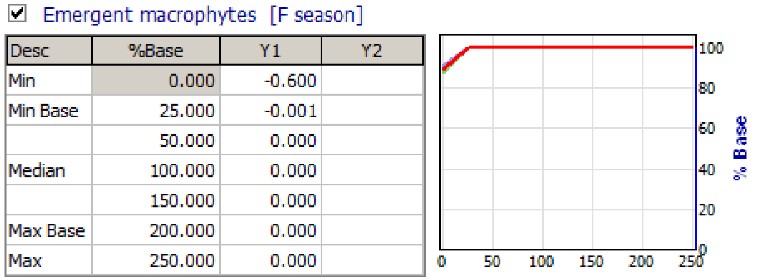
6.10.7 Gobies *C. mossambica, S. sibayi, G. callidus*

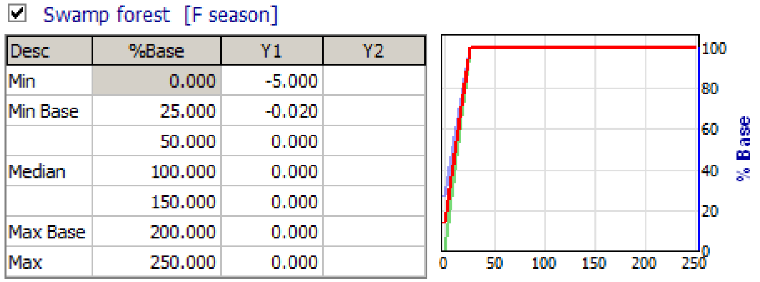
<table>
<tr><td colspan="2">Gobies <i>C. mossambica, S. sibayi, G. callidus</i></td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>10.422</td><td>-1.100</td><td></td></tr>
<tr><td></td><td>11.318</td><td>-0.400</td><td></td></tr>
<tr><td>Median</td><td>12.214</td><td>0.000</td><td></td></tr>
<tr><td></td><td>13.468</td><td>0.800</td><td></td></tr>
<tr><td>Max Base</td><td>14.723</td><td>1.500</td><td></td></tr>
<tr><td>Max</td><td>16.932</td><td>1.900</td><td></td></tr>
</table>
</td><td>Three species of goby occur in Lake Sibaya; <i>C. mossambica, S. sibayi</i> and <i>G. callidus</i> They have wide habitat niches and are all feeders on benthic invertebrates. As such their broadest dependency is on water area.</td><td>Moderate</td></tr>
</table>

6.10.8 Number of species

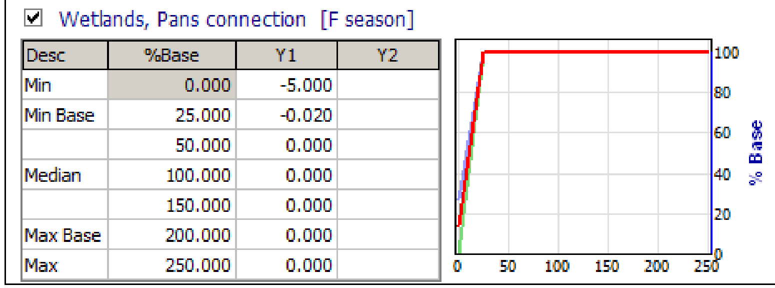
<table>
<tr><td colspan="2">Number of species</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>10.422</td><td>-0.001</td><td></td></tr>
<tr><td></td><td>11.318</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>12.214</td><td>0.000</td><td></td></tr>
<tr><td></td><td>13.468</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>14.723</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>16.932</td><td>0.000</td><td></td></tr>
</table>
</td><td>There are 18 species in Lake Sibaya (Bruton 1979a). All have different requirements of habitats, water quality and water level for their continued existence in the system. Most are nevertheless robust and will persist in the lake even under relatively extreme conditions. Water area will be limiting at extreme lake water levels.</td><td>Moderate</td></tr>
</table>

<table>
<tr><td colspan="2">Number of species</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Submerged, rooted veg [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.600</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.001</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>

</td><td>Sensitive and vulnerable species include those with dependencies on aquatic vegetation, especially submerged macrophytes.</td><td>High</td></tr>
<tr><td>

☑ Emergent macrophytes [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.600</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.001</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>

</td><td>Sensitive and vulnerable species include those with dependencies on aquatic vegetation, including emergent macrophytes.</td><td>Moderate</td></tr>
<tr><td>

☑ Swamp forest [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.020</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>

</td><td>The most sensitive and vulnerable species are those with dependencies on aquatic vegetation, and lake associated swamps and wetlands.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Number of species</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


☑ Wetlands, Pans connection [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.020</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>

</td><td>The most sensitive and vulnerable species are those with dependencies on aquatic vegetation, and lake associated swamps and wetlands.</td><td>High</td></tr>
</table>

6.10.9 Fisheries biomass

<table>
<tr><td colspan="2">Fisheries biomass</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>Mozambique tilapia (35%)
Sharptooth catfish (28%)
Multispined climbing perch (<1%)
Barbs and topminnows (1%)
Pelagic species (<1%)
Other cichlids (35%)
Gobies (1%)</td><td>Weightings were applied to the various species that are fished in the lake as estimated % contributions to the biomass of fish caught and eaten. Initially % contributions (by abundance) of different fishes to different fishing methods (*umono* baskets, *fonya* drives, rod and line, spearing and clubbing, migrations) were estimated and multiplied by respective relative body weights. Contribution of different fishing methods to total biomass caught and eaten was estimated and in this was an estimated % contribution of different fishes to total biomass harvested.</td><td>Moderate</td></tr>
</table>

6.11 Assumptions and limitations

The follow assumptions and limitations apply:

- Little data could be sourced on actual or even relative fish abundances of fishes in Lake Sibaya, despite the wealth of information available on species biology in the lake. While the July 2015 field visit was valuable in allowing first-hand experience of the system to be gained, sampling effort was limited and biased to one sampling method at a time when fish abundances in the habitats sampled were probably naturally low. Quantitative data on fishes in the system are therefore lacking. Extrapolation from other systems is made difficult by the uniqueness of Lake Sibaya in South Africa. It was assumed that data on fish composition collected during the 1970's remains relevant to the fish diversity present today.
- Lake Sibaya is likely to be sensitive to nutrient inputs and its response to such inputs will vary depending on lake water level. The lake is oligo-mesotrophic but primary productivity and the relative roles and sensitivities of phytoplankton and microphytobenthos are not well understood. These components were not included in the EWR assessment, and neither were the primary consumers (macrobenthos and zooplankton). These biota are all important elements of the diets of fishes in the lake.
- The impacts of the invasive gastropod *Tarebia granifera* on the lakes fishes are not understood. Given the abundance of this gastropod in the lake it is plausible that some impact to the fish assemblage has occurred. Grazing of *T. granifera* in shallow water terrace habitats may well have reduced food availability for juvenile cichlids, and *O. mossambicus* in particular.
- Waves and currents are likely to be strongly influenced by lake water level and both play a significant role in the morphology of the lake. The morphology of the lake in turn plays a major role in the ecology of the system (including its ichthyology). The lack of understanding of the potential impacts of lake water level on lake morphology therefore remains a major limitation to the study.
- Response curves developed and the overall assessment made for the purposes of this study were informed by limited understanding of hydrological and lake water level relationships, which may not be accurate for scenarios that deviate considerably from the present situation.

6.12 Raw fish catch data

Seine net catches per unit effort (fish per haul, Table 6.6) from sampling conducted in Lake Sibaya on 14 – 16 July 2015. Site locations are given in Figure 6.1.

Table 6.6 Seine net catches per unit effort

Species	**MS1**	**MS2**	**MS3**	**MS4**	**MS5**	**MS6**	**MS7**	**MS8**	**MS9**	**MS10**	**MS11**	**MS1**
No. of hauls	3	2	2	2	2	2	2	1	2	2	2	2
Atherina breviceps	90.7	12.5	93.0		71.5		90.0	398.0	141.5	65.0	4.0	8.0
Gilchristella aestuaria				11.5								
Barbus viviparus	0.3											
Glossogobius callidus								1.0		0.5		0.5
Silhouettea sibayi												2.0
Oreochromis mossambicus				96.5							77.5	
Pseudocrenilabrus philander						0.5				1.5		2.0
Tilapia rendalli				2.0	1.5	3.0		8.0	4.5	3.0		14.5
Tilapia sparrmannii	1.7	17.5	1.0			3.0	1.0		1.5	4.5		2.5

6.13 Acknowledgements

The assistance of Mr Molefi Mazibuko of the Department of Water and Sanitation is acknowledged, with gratitude.

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7 HERPETOFAUNA AND SEMI-AQUATIC MAMMALS

7.1 Introduction

This Section comprises the summary report for the herpetofauna and semi-aquatic mammals, and provides:

- An overview of the study area, with focus on delineation of homogenous areas for herpetofauna and semi-aquatic mammals;
- For the EWR zones:
    - EcoClassification assessments for the herpetology and semi-aquatic mammals, with supporting evidence;
    - the DRIFT indicators chosen, and reasons therefore;
    - the relationships between the selected indicators and water level or other drivers;
- Data and the details of any analyses performed.
- EcoSpecs and monitoring actions required to describe and monitor the recommended Ecological Status with respect to the herpetology and semi-aquatic mammals.

7.2 Description of the study area, with relevance to herpetofauna and semi-aquatic mammals

Lake Sibaya is a Ramsar listed ‘Wetland of International Importance’ and is part of the iSimangaliso Wetland Park World Heritage Site. The Lake has an average surface area of 65 km^2 and a maximum depth of 41 m (Pitman & Hutchison 1975). For amphibians, reptiles and semi-aquatic mammals much of the lake is not accessible as it is too deep, or too exposed and is often affected by severe wind-generated wave action. Hippos (*Hippopotamus amphibius*) can venture into the relatively shallow waters (up to a maximum of about 7 m deep) and the adult crocodiles into the deeper and more open water. The habitat most used by the animals under review is the shallow water associated with the 125 km shoreline of the lake (Hill 1979). Much of this shoreline has a fringe of emergent vegetation also present in the distal ends of the inlets; many of which are drowned interdune valleys which accumulate organic sediments with dense swamp vegetation.

Amphibians, reptiles and mammals of Lake Sibaya all rely on the interface where the lake meets the land. The dryland to the east has steep dune slopes covered in forest. Elsewhere, where the topography is gentle, there are permanent and ephemeral pans. These are used extensively by these animals. The zone of influence of the lake extends further in the case of hippos which can move distances of up to 10 km from the lake when they graze at night (Eltringham 1999).

The lake and its surrounds provides suitable habitats for species that require open water, sheltered vegetated shorelines, adjacent shallow permanent and ephemeral pans and hygrophilous and dry grasslands.

7.3 Literature review

Information relating to the presence and abundance of reptiles and amphibians was obtained from Bruton (1979 & 1980) and from Kyle (pers. comm.). In addition information relating to distribution and conservation status was obtained from the Reptile Atlas (Bates *et al*. 2014) and from the Frog Atlas (Minter *et al. 2*004). There are more than 30 amphibian and more than 60 reptile species in the Lake and its adjacent groundwater catchment area making this one of the richest areas in South Africa for both reptiles and amphibians.

7.3.1 Amphibians

Frogs are sensitive to pollution and changing water levels - both of which can seriously affect their life cycles and thus abundance. Some species have been used as environmental indicators but, in this context, no single species was suitable to act as an indicator of change in water levels. Therefore a guild of species that occupies the lake shoreline vegetation was selected. The frogs in this guild include the Bufonidae (toads), the Hyperoliidae (reed frogs and Kassinas) and the Ptychadenidae (grass frogs) (Du Preez and Carruthers 2009).

7.3.2 Reptiles

There are four major taxa of reptiles associated with Lake Sibaya: terrapins, snakes, lizards and crocodiles (Bates *et al.*2014).

Two species of terrapin are probably associated with the lake but all usually live in shallow vegetated areas and probably cannot survive in open water or sandy shorelines which lack vegetation. They are not common and little is known about their biology in Lake Sibaya. Several snakes are to be found around the margins of the lake and many feed on amphibians or small fish. Of these the most obvious are probably the species of *Philothamnus* (green water snakes) and *Natriciteres* (marsh snakes), which stalk small frogs in the very shallow vegetated margins of the lake. Larger snakes include the rock python (*Python natalensis*) and forest cobra (*Naja melanoleuca*) both of which are excellent swimmers. The former has been found trapped more than two metres under the water in the lake while the latter often stalks frogs and birds along the reedy margins of the lake. The only water-dependent lizard is the Nile monitor that is common round the margin of the lake. While it can predate upon crocodile nests its most common foods are the frogs and small fish it catches in the shallow margins of the lake. None of the terrapins, snakes or lizards was considered suitable to be useful as an indicator of changes in lake water levels. The Nile crocodile, which is totally reliant on the lake, is a species for which much data exists and it was selected as an indicator for this reason.

Much of the information relating to crocodiles (Figure 7.1) was obtained from Combrink (2004) and other data on crocodile censuses and nesting from unpublished reports provided by Ezemvelo KwaZulu Natal Wildlife.

Figure 7.1 A young Nile crocodile

The Nile crocodile is listed by the IUCN as 'Vulnerable'. In the 2015 census only 25 crocodiles were counted in Lake Sibaya. Due to severe undercounting, the population of crocodiles over 1.2 metres may be regarded as being closer to somewhere between 50 and 100.

Young Nile crocodiles hatch from hard shelled eggs and are usually carried by their mothers to nearby sheltered waters where they are guarded for up to two months. They then become independent and at 1.2 m in length are solitary in nature. They initially grow up to 30 cm per year to maturity; at 2.5 m in females and 3 metres in males. Mating takes place in shallow water during July and August. In the early breeding season males attract females by displaying mating behaviour and vocalisation. At night, females excavate nests, 30 to 45 cm deep, in loose soil/sand and lay 16 to 80 white hard shelled eggs, 2 months after mating. The young hatch after being incubated by the mother for three-months and are removed from the nest by the mother. The young stay together in a "crèche" for 6-8 weeks during which time the mother often remains among them and will violently attack any potential threat.

A summary of breeding requirements with specific reference to habitat provided at Lake Sibaya:

- Suitable soils for nest digging. Lake Sibaya is surrounded by soft sands suitable for crocodiles nesting.

- Cover for nesting sites. For this reason the nests are in the tree-line, but with receding levels there are large areas of exposed sand banks between nest sites and open water.
- Shaded/unshaded nest sites. It is necessary for nest sites to be partially shaded. As lake levels drop it is probable that nest sites may become progressively more exposed.
- Cover for hatchlings to reach water. It is dangerous for hatchlings to have to move through extensive open areas to reach water as this exposes them to increased predation.
- Undisturbed nest sites. Disturbance by humans and animals, including cattle and goats, can result in reduced nesting success.
- Nesting sites near water. Nests can be up to 150 m from the water, but this distance can result in less protection of nests and reduced success of hatchlings reaching water safely.
- Undisturbed nesting sites. Continued disturbance of females at nest sites will drive them away. The hatching crocodiles in the nest need assistance from the mother to successfully escape from the underground nest.
- Nesting areas unlikely to flood. If nests are inundated by rising water levels all the eggs/young will die.

Once the young leave the “crèche” the juvenile crocodiles often dig a burrow up to 3 m long and spend much of the first 4 to 5 years of their life in or near the burrow. Initially the growth rate is about 30 cm per year up to 1.2 m in length and then slows to about 2.5 cm per year. After the hatchling period the juveniles spread out into the shoreline vegetation, backwaters and inlets. When they are sexually mature males develop a dominance hierarchy at the start of the breeding season (May). They will then mate with females who will then seek out a suitable nesting area to dig their nest, usually in November.

A summary of growth requirements of hatchlings with specific reference to habitat found at Lake Sibaya:

- “Crèche sites” are sheltered areas where hatchlings are safe from predation. These are likely to be mainly in the sheltered inlets or backwaters in which very small crocodiles would be hidden from predation.
- Burrows in which the crocodiles spend a lot of time. These burrows are in the banks or in consolidated vegetation.
- Vegetation-covered water margins in which young crocodiles are safe from avian and other predation.
- Areas to disperse away from the adults, which are territorial and also potentially cannibalistic. If the population is large enough this may be a density-dependent mechanism which caps the numbers of crocodiles.
- A suitable food supply in the form of insects, snails, frogs, crustaceans and small fish away from areas inhabited by adult crocodiles.

Juveniles tend to eat larger prey items and this includes fish, crabs, terrapins, reptiles, birds and mammals. Proportions of the different foods taken vary on availability but also on the availability of small inlets in which to corner shoals of fish. As they grow larger crocodiles eat progressively larger prey but at Lake Sibaya large prey are in short supply. It is therefore likely that even large crocodiles in Lake Sibaya eat mostly fish, including a large proportion of catfish, plus birds and some reptiles such as water monitors. Carrion will also be eaten as will domestic stock (cattle and goats). There are no recently reported fatal attacks on humans at Lake Sibaya. Larger crocodiles are protected to ensure breeding and recruitment.

7.3.3 Semi-aquatic mammals

The mammals associated with Lake Sibaya, listed by Bruton (1979), are given in Table 7.1.

Table 7.1 Semi-aquatic mammals of Lake Sibaya (Bruton 1979)

Common name	Scientific name
Hippo	*Hippopotamus amphibius*
White-tailed mongoose	*Ichneumia albicaudata*
Water mongoose	*Atilax paludinosus*
Vlei rat	*Otomys irroratus*
Marsh rat	*Dasymys incomtus*

Of these hippos were selected as useful indicators of water level change. Hippos are an iconic component of the Lake Sibaya ecosystem. Within the lake they prefer water in the 1 to 2 m depth range for lying up during the day (Taylor 2013). They also require sand banks for basking during the day. At night they require grasslands for grazing – and most used are the hygrophilous grasslands where the water table is close to the surface. It is these grasslands that will be altered should the groundwater table be lowered by abstraction.

As ecosystem drivers, their paths through wetland vegetation create pathways for other species – such as fish and birds. They are also particularly important in the nutrient-poor Lake Sibaya as they transfer nutrients, as urine and faeces, from the land into the lake (Bruton 1979).

From an initial count of 42 in 1956, the hippo population had increased to 152 by 1986 but the population has dropped again to 49 at 2015. This decline has accelerated since 2012 and is expected to continue as the human presence around the lake increases. The boundary of the iSimangaliso Park is along the western shoreline of Lake Sibaya . Grazing within the park is severely limited and most of the hippos graze beyond the park boundaries. This puts them in conflict with humans and threatens their viability (Taylor 2010).

A summary of needs for a sustained hippo population in Lake Sibaya is provided below:

- **Sufficient habitat and microhabitats**. These include suitable lie-up sites within the lake – on a firm substratum at a preferred depth of about 1.4 m. These sites should have some shelter from wave action and be away from human disturbance. Preferably the hippos should be able to leave the water during the day to bask in the sun, especially during winter (Taylor 2013).
- **Food availability**. There should be food of sufficient quality and quantity within a reasonable distance from the Lake. Hippos will usually feed a maximum of between 5 and 10 km from their daytime lie-up sites.
- **Intraspecific constraints** (Territoriality). Adult male hippos establish daytime territories in the water and attract females to these (Klinger 1991). This behaviour spaces out the groups and may become density-limiting if the hippo population is high.
- **Hippo-human interactions**. Hippos avoid contact with humans whenever possible both during the day and night. However, they raid crops and inevitably this leads to conflict with humans. Hippos are harassed and snared around much of Lake Sibaya.
- **Special habitat requirements**:
  - The female needs dense vegetation for shelter when she gives birth and as a nursery site for one week before rejoining the herd
  - In dry periods hippos feed in dry pan-bottom areas where grass is green and nutrition levels are high. In wet periods (when the pans fill up) hippos have to feed further afield – and often on grass of lesser quality.

Should afforestation increase in the vicinity of Lake Sibaya, plantations will displace grazing areas for cattle as well as for hippos. Should the groundwater table drop, then the quality of the grazing is reduced as hygrophilous grasslands dry up.

7.4 Description of the EWR zones

Hippo and crocodiles data were collected during the EKZNW censuses and crocodiles nest surveys were used. Frog data were obtained from the literature. No field surveys were conducted for this study.

The main habitats available are shown in Figure 7.2:

- (i) the open deep water is not used by frogs, hippos or small crocodiles and only to a small extent by adult crocodiles;
- (ii) the shallow underwater terraces are used by crocodiles. The hippos often lie-up on the lakeward edge of these terraces where they drop off into deeper water (Figure 7.3);
- (iii) the shoreline and narrow band of emergent vegetation is by far the most important habitat for small crocodiles and frogs; and
- (iv) the grasslands peripheral to the lake where the hippos feed.

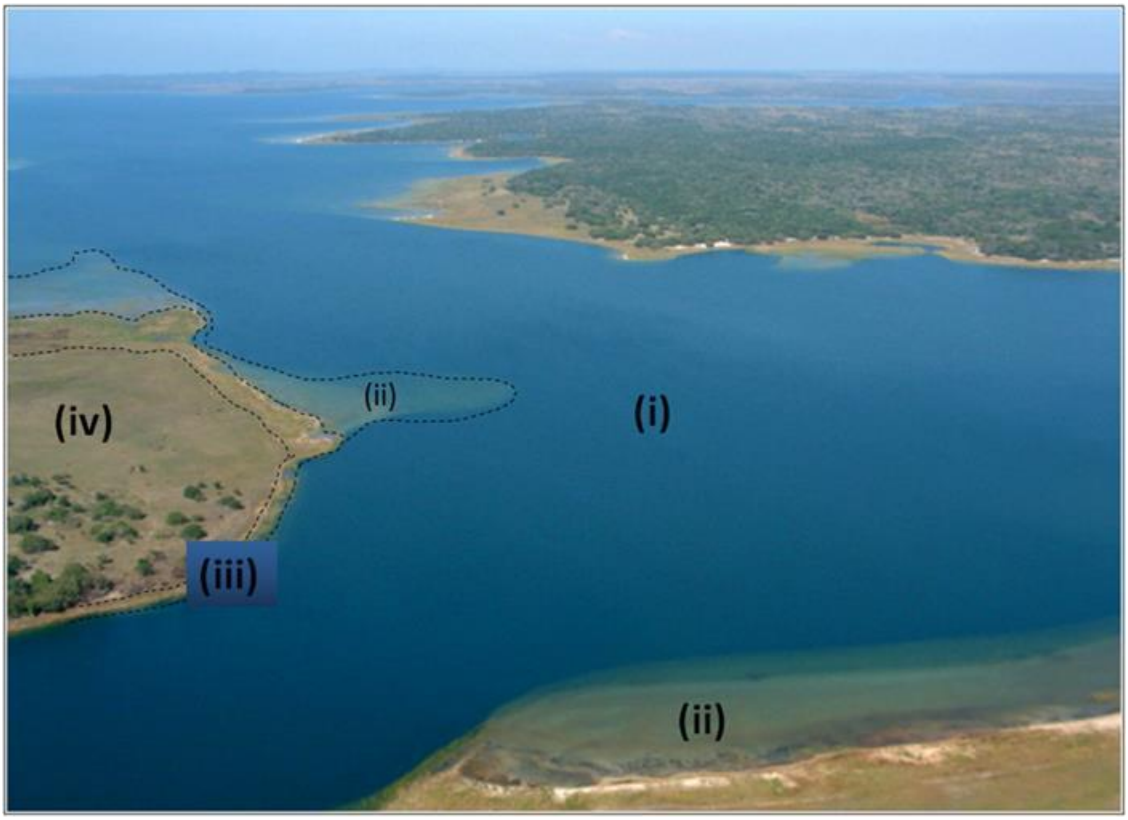


Figure 7.2 Portion of the North Arm where it joins the Main Basin

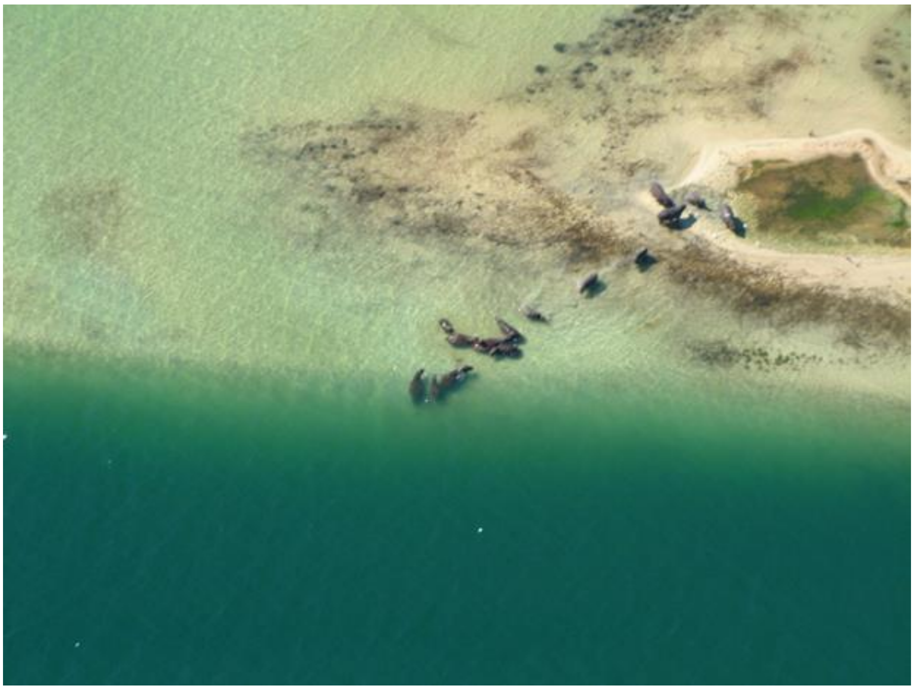
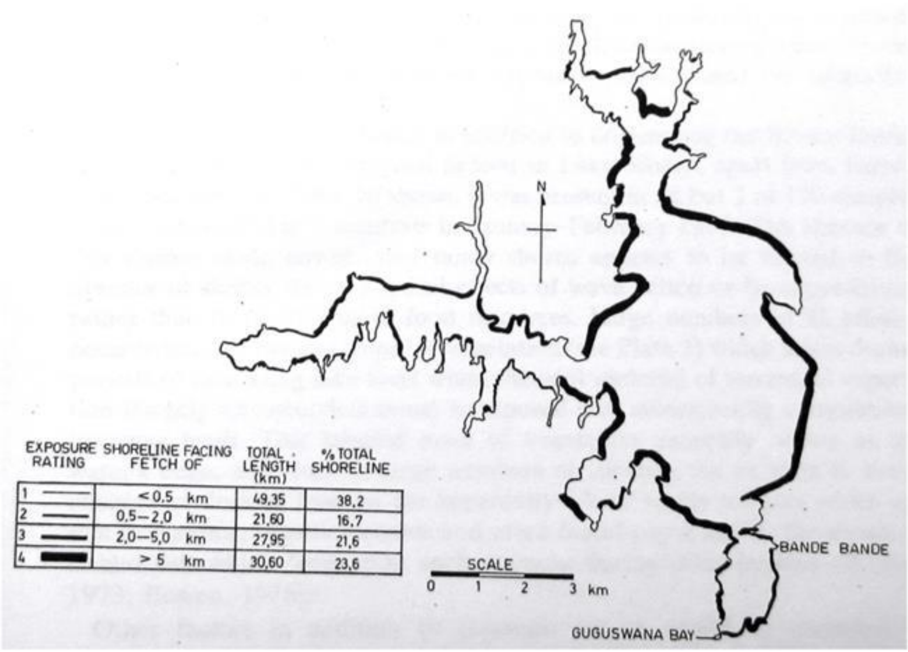


Figure 7.3 Hippos on the edge of Lake Sibaya

Different shorelines of the lake experience different intensities of wave action (Figure 7.4) but is most severe in the Main Basin.



EXPOSURE RATING	SHORELINE FACING FETCH OF	TOTAL LENGTH (km)	% TOTAL SHORELINE
1 ─	<0,5 km	49,35	38,2
2 —	0,5–2,0 km	21,60	16,7
3 ━	2,0–5,0 km	27,95	21,6
4 ▬	> 5 km	30,60	23,6

Figure 7.4 Map showing exposure of shorelines to wave action (Hart 1979)

A map of beaches compiled from 1964 (water level 1.7 m above datum) and 1977 (water level 4.6 m above datum) may be compared to relatively lower current (2015) water levels whereby most of the dark areas on the map are currently dry beaches – and new shallow-water terraces are now present (Figure 7.5).

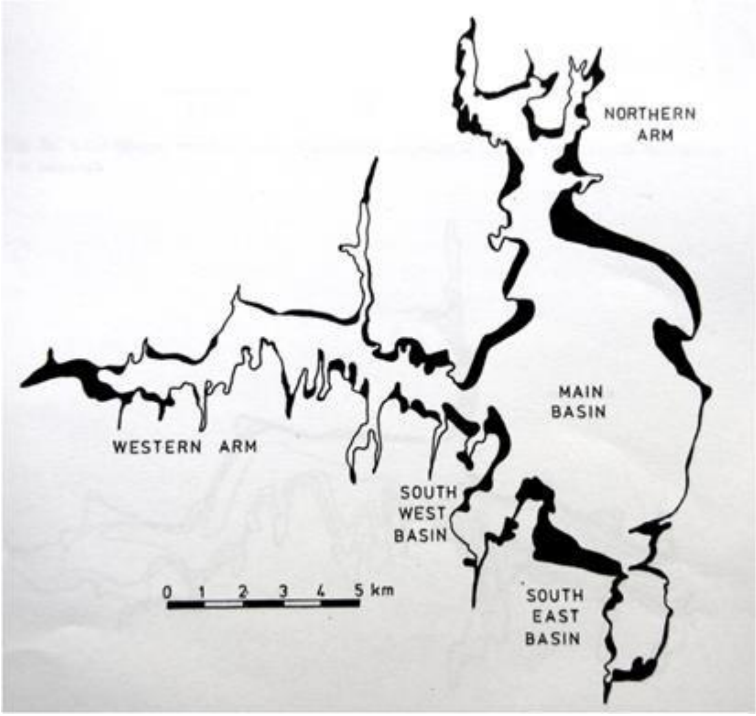


Figure 7.5 The locations of the main shallow-water terraces Hill (1979)

Data for this study were collected at 10 sites (Figure 7.6).

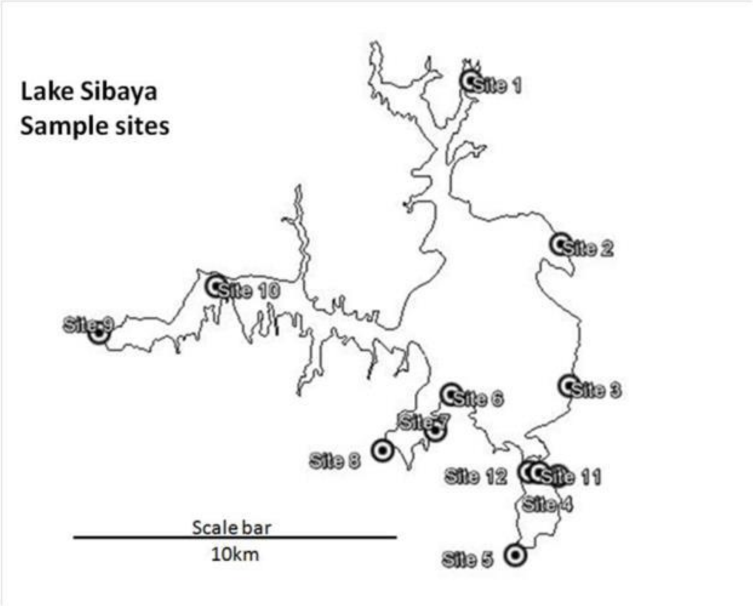


Figure 7.6 Location of the 10 sampling sites

Pans are important for hippos and crocodiles and the regional frog populations (Figure 7.7).

Figure 7.7 Lake Sibaya in the distance with a pan in the foreground

7.4.1 EWR Zone 1 – Southern Basin

This Basin has relatively exposed and bare shorelines but there are also organic deposits with rich vegetation. The Southern portion of this basin (Guguswana Bay, Figure 7.8) has the main pump station. The whole of the basin is subject to human disturbance, which drives the crocodiles and hippos away.

Figure 7.8 The connection between the South Basin (top right) and Main Basin (lower left) closed in early 2015 (Combrink 2013)

Frogs: The vegetation at the pumphouse in Guguswana Bay is habitat likely to have a rich frog fauna; there is little of this elsewhere in the Basin.

Crocodiles: At Bande Bande there is a cormorant colony in a patch of trees that is also the basking and nesting site for a large crocodiles that likely feeds on the occasional cormorant nestling that falls out of the colony.

Hippos: Hippos are present – but in relatively low numbers. To the east of the bay are steep forest-clad dunes but most of their feedings takes place in the grasslands to the west and the south-west.

7.4.2 EWR Zone 2 – Main Basin

The main basin contains the deepest part of the lake but is also characterised by large areas of shallow terraces. .Where there is no vegetation the exposed shorelines form suitable basking sites for both hippos and crocodiles but only in the absence of wave action.

Frogs: Where the shorelines are protected there is a fringe of emergent vegetation along the land-water interface that provides habitat for frogs.

Crocodiles: The crocodiles prefer the western and southwestern shores where there are fewer people and they can patrol the drop-off slopes at the interface between the shallow and deep waters. Where the shorelines are protected there is a fringe of emergent vegetation along the land-water interface that provides habitat for small crocodiles.

Hippos: The hippos prefer the western and southwestern shores where there are fewer people. Where less exposed, the hippos tend to lie-up at the edge of the terraces at the drop off to deeper water where they can find water at their preferred depth of 1.4 m for day-time lie-up (Taylor 2013). The hippos feed in the grasslands to the north-east of the Main Basin in the vicinity of the Mabibi settlement. They also feed in the grasslands to the north, north-west and south-west. There is little feeding habitat in the dunes to the east.

7.4.3 EWR Zone 3 – Northern Arm

The Northern Arm has a convoluted shoreline and is reasonably well sheltered from the wind. In addition the inlets have rich plant growth in their distal proximities.

Frogs: The emergent shoreline vegetation forms suitable habitat for frogs.

Crocodiles: The emergent shoreline vegetation forms suitable habitat for small crocodiles. The vegetated distal ends are likely to be an important “crèche” habitat for crocodiles and it is expected that juvenile crocodiles would shelter in burrows in this area. Crocodiles are relatively common along the western shore.

Hippos: Hippos are relatively common along the western shore. There is good grazing in all directions.

7.4.4 EWR Zone 4 – Southwestern Basin

This is a relatively small basin. Its shorelines are exposed to wind and wave action but where there is some protection from this, the shoreline vegetation provides habitat for small crocodiles and frogs.

Frogs: The emergent vegetation provides habitat for frogs.

Crocodiles: The emergent vegetation provides protection for hatchling and juvenile crocodiles. The basin is used by adult crocodiles as it is a good locality to catch fish at the shoreline.

Hippos: There is human disturbance here and the hippos tend to be skittish. Hippos are able to feed to the south and west as both these areas are low-lying and contain pans and hygrophilous grasslands.

7.4.5 EWR Zone 5 – Western Arm

The Western Arm is distinct from the rest of the lake. Having an east-west orientation it is not as affected by the strong northerly and southerly winds as is the rest of the lake. It is also an area with comparatively little human disturbance (with the exception of the extreme westerly end of the water body at Mseleni). With all the shoreline vegetation and rich ends of the inlets (the latter comprsing drowned inter-dune valleys), there is an abundance of emergent vegetation and swamp.

Frogs: The abundance of bay swamps and emergent vegetation provides good frog habitat.

Crocodiles: The rich emergent and swamp vegetation provides habitat for small crocodiles and the relatively undisturbed shorelines are suitable for adults.

Hippos: Hippos are concentrated along the relatively undisturbed shorelines and feed in the grasslands and pan vegetation to the north and south of the basin.

7.5 EcoClassification of the lake for herpetofauna & semi-aquatic mammals

The purpose of EcoClassification is to gain insights and understanding into the causes and sources of the deviation of the Present Ecological State (PES) of biophysical attributes from the Reference Condition (Kleynhans and Louw 2007). Although the lake is divided into five areas for the purpose of this study all the basins, with respect to crocodiles, hippos and frogs, were classified the same due to the mobility of these organisms and the connectivity of the five areas of the lake.

The Baseline Condition (present day) populations of both hippo and crocodile are considerably reduced from their previous natural population sizes due to poaching and loss of grazing habitat for the hippos and nesting habitat for the crocodiles. In addition, the widespread presence of the alien plant *Myriophyllum spicatum* provides an over-abundance of habitat for the snail *Tarebia granifera,* which competes with other (possibly more palatable) molluscs possibly fed on by the hatchling crocodiles. Frog diversity and population size is believed to have been relatively unaffected by changes in the lake.

Under Reference Conditions population sizes of hippo and crocodile would have been larger due to less human disturbance, and less competition for grazing by domestic stock and fewer plantations of woody species. The abundance and species richness of frogs are believed to be in the same state as at present.

The hippos and crocodiles are both IUCN listed as “Vulnerable” and are both experiencing strong downward trends in abundance.

The EcoClassification for the lake overall, that is extrapolated to the five areas (EWR zones) is Category C.

7.6 Results

No field surveys were conducted for this study and results provided for crocodile and hippo are summarised from that of EKZNW.

7.6.1 Crocodiles (*Crocodilus niloticus*)

There are between 250,000 and 500,000 Nile crocodiles worldwide. Of these, ~7000 are estimated to occur in South Africa (with a length greater than 1 m), of which ~3000 are located in KwaZulu Natal and ~1200 in the iSimangaliso Park. The last crocodile count for 2014 indicated ~25 in Lake Sibaya, with the highest recorded number being 107 in 1990 (Table 7.2). Numbers are significantly lower in the last 15 years than from 1980-1993.

Table 7.2 Crocodile census data for Lake Sibaya (EKZNW)

Year	Count		Year	Count
1980	60		2004	29
1985	67		2007	22
1986	75		2008	7
1987	62		2009	7
1988	92		2010	21
1989	57		2011	40
1990	107		2012	38
1993	52		2013	21
2003	36		2014	25

The distribution of crocodiles in the Lake is shown in Figure 7.9 (Combrink *et al.* 2011b).

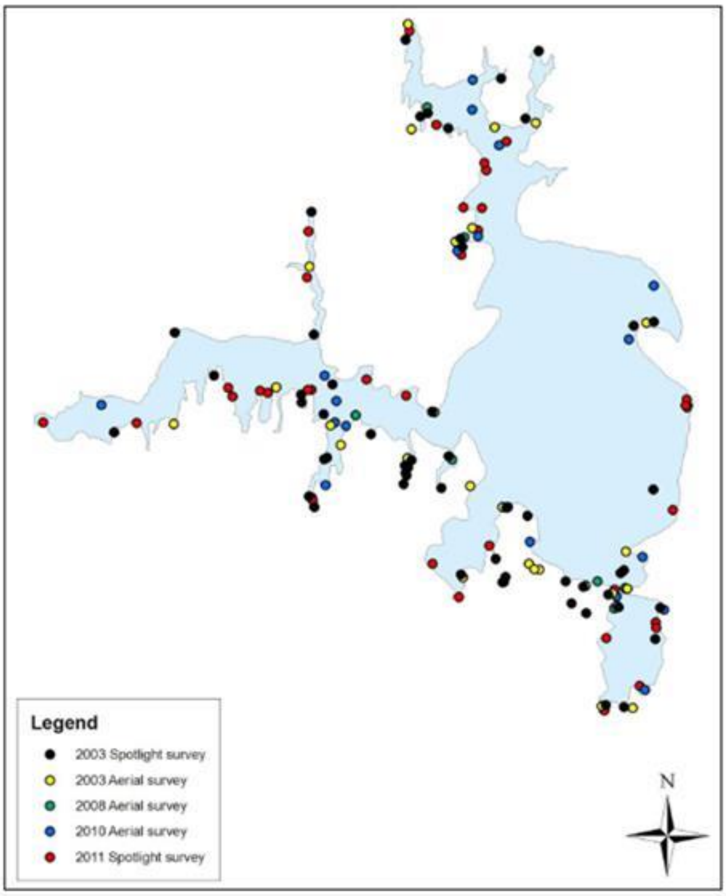


Figure 7.9 Crocodile distribution across Lake Sibaya (EKZNW)

Crocodile counts are difficult and it is believed that the current counts underestimate the present day numbers by up to half as a result. Nonetheless Combrink (2004) provides data that show the overall decreasing trend Figure 7.10.

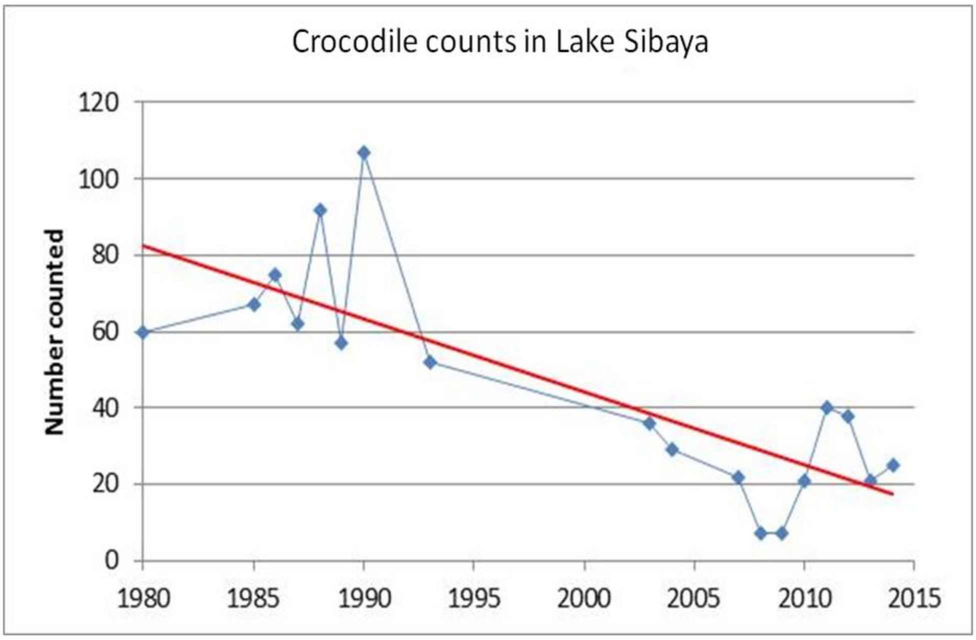


Figure 7.10 Crocodile abundance in Lake Sibaya (Combrink 2004)

The number of crocodiles spotted appears to increase as water levels rise (Figure 7.11). However this is likely to be a aberration as the population decrease has occurred simultaneously with the lowering of the water level in the lake.

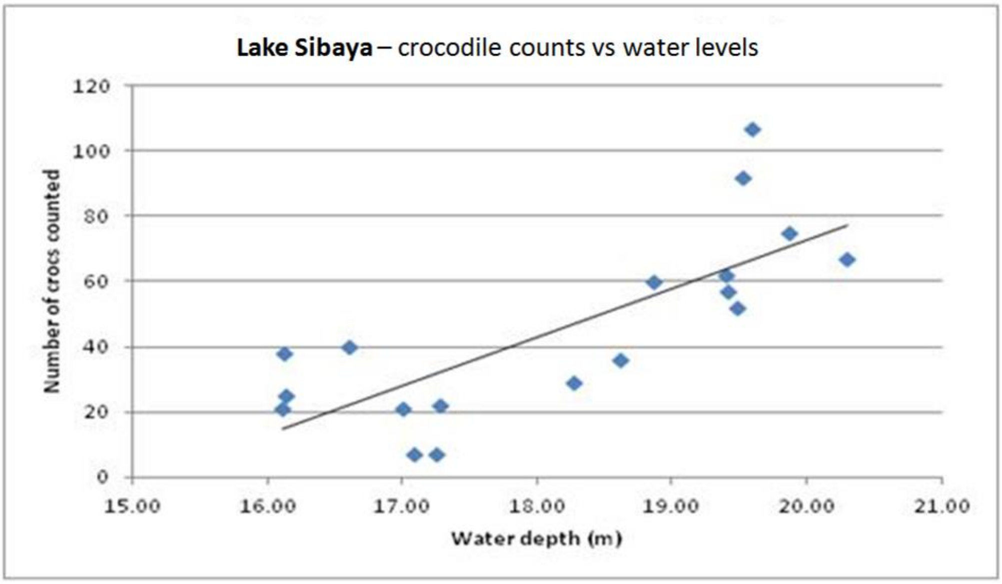


Figure 7.11 Crocodile abundance increases as lake depth increases (Combrink 2004)

Crocodile numbers have declined very rapidly over the past several years while water levels have been dropping (Figure 7.12). It may be that the crocodiles are more exposed to poaching when beach areas are wider and more accessible.

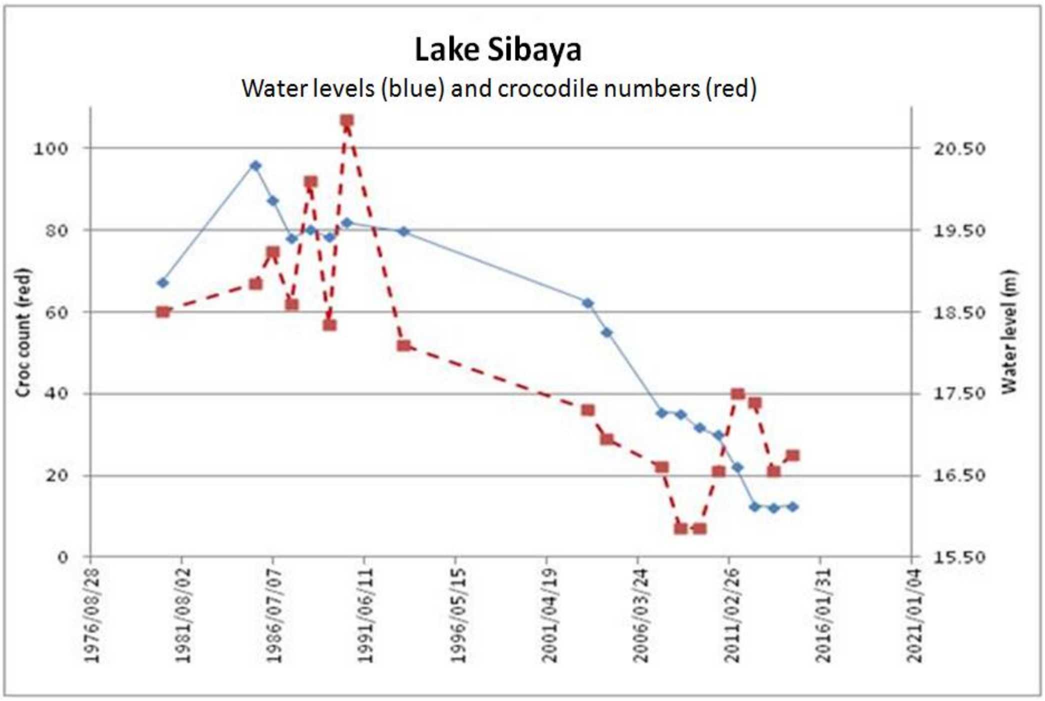


Figure 7.12 Crocodile abundance and Lake Sibaya water levels

7.6.2 Hippos (*Hippopotamus amphibious*)

Hippos live for up to 35 years and begin to breed between 7 and 15 years of age. The gestation period is eight months and the inter-calving interval is 2 to 3 years. At Lake St Lucia they suffer average mortality rates of 4% per annum but these may be as high as 45% for infants (Table 7.3).

Table 7.3 Mortality of hippos at Lake St Lucia (Taylor 2013)

Age class	Survival (%)
0-1 year	55
1-2	85
3-adult	96-97

The population growth rate for hippos is theoretically 10 % per annum at maximum. Hippo numbers for Lake Sibaya are provided below (Table 7.4).

Table 7.4 Population counts at Lake Sibaya (EZKNW)

Year	Hippo		Year	Hippo
1956	42		1982	136
1957	21		1983	133
1958	40		1984	125
1964	47		1985	146
1965	44		1986	152
1967	54		1995	125
1968	66		1996	115
1969	62		1997	119
1970	60		1998	93
1971	61		2002	90
1972	64		2003	91
1973	93		2004	116
1974	82		2007	122
1975	60		2008	123
1976	40		2012	81
1979	115		2013	69
1980	115		2014	67
1981	129		2015	49

From the late 1950s to the mid-1980s hippo numbers were rising (Figure 7.13). The rise is ascribed partly to better conservation protection and partly to the influx of hippos that were displaced from pans and moved into the lake. The trend since the late 1980s has been a severe and progressive decline.

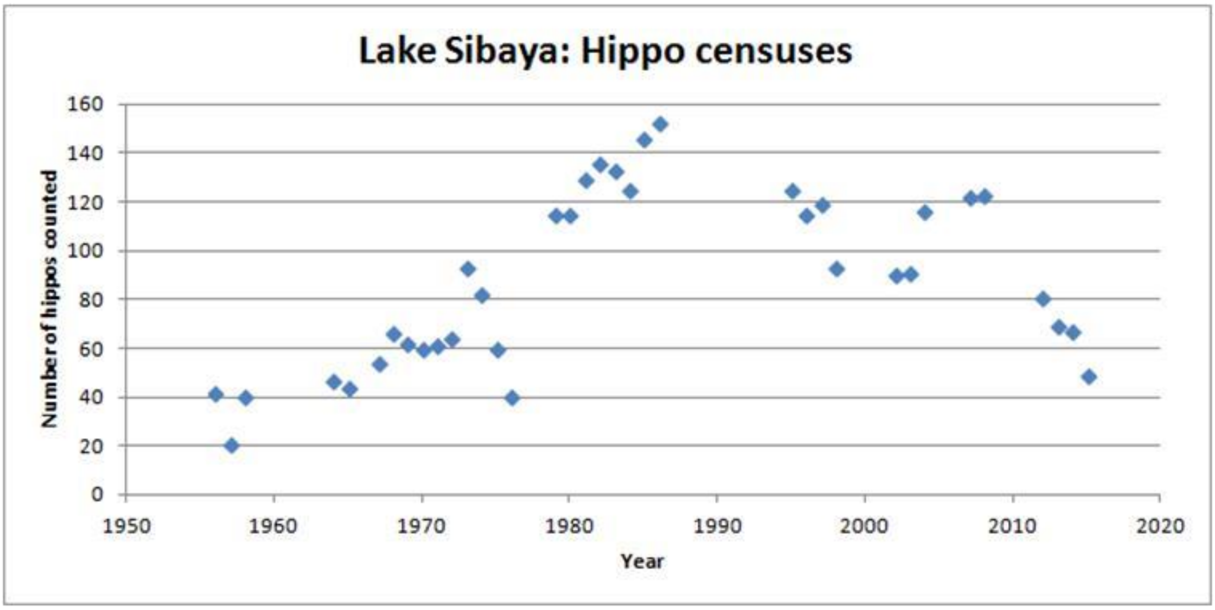


Figure 7.13 Lake Sibaya hippo census counts

The hippos are concentrated in the southern portions of the Lake and especially in the Western Arm. In many places they are in close proximity to human settlements (Figure 7.14 and Figure 7.15) which leads to increased risk of hippo-human conflicts.

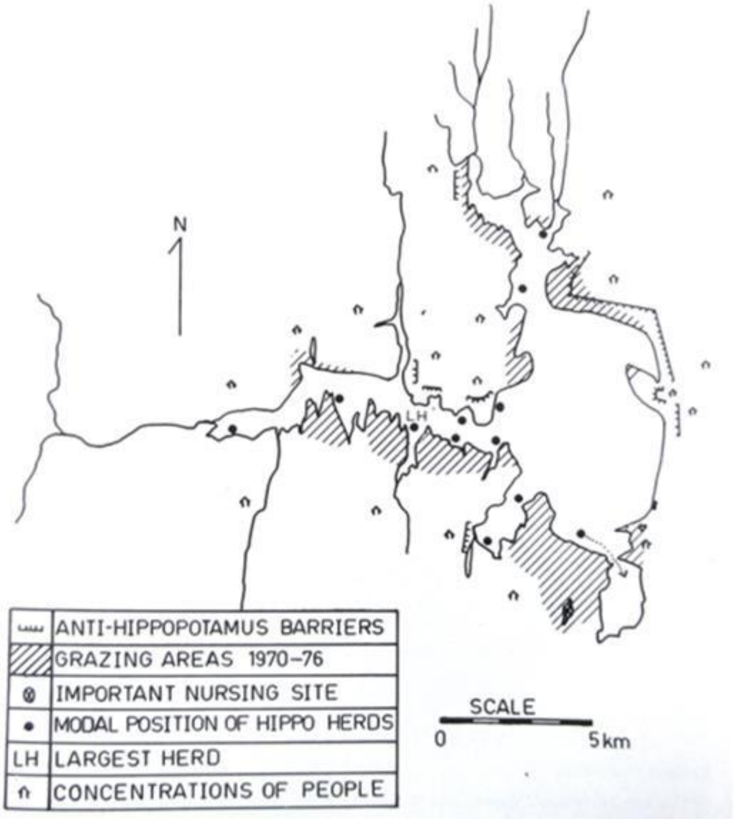


Figure 7.14 Distribution of hippo and people at Lake Sibaya: 1970-1976 (Bruton 1979)

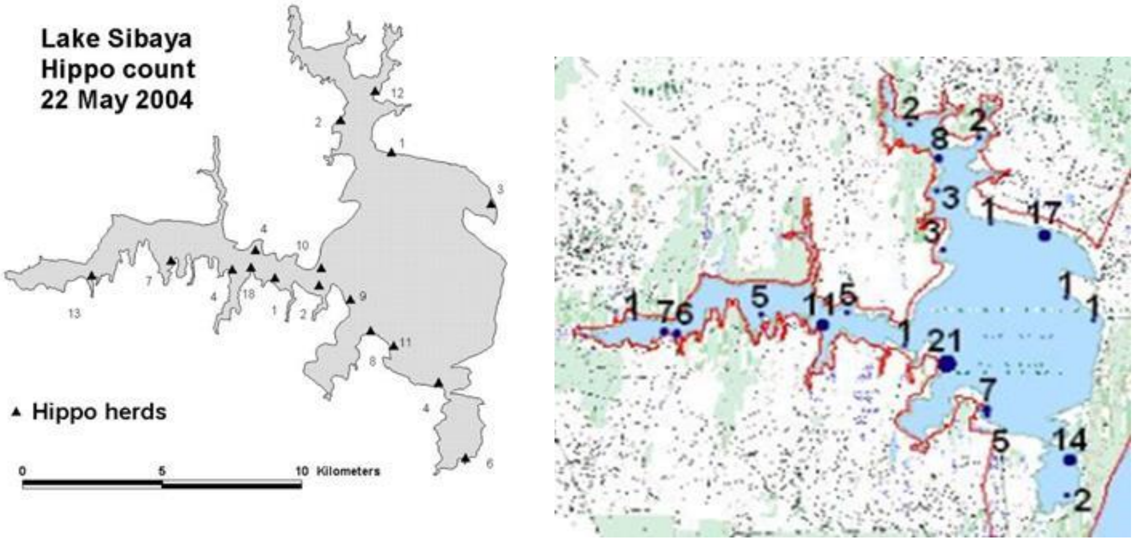


Figure 7.15 Counts (a) from 2004 (=116) and (b) from 2008 (=123) (EKZNW)

7.7 Identification of indicators

7.7.1 Indicator list for herpetology and semi-aquatic mammals

The herpetofauna and semi-aquatic mammals selected as indicators and reasons for their selection are provided in Table 7.5 while their expected response to changing water levels is provided in Table 7.6.

Table 7.5 Indicators and reasons for their selection

Indicator	**Reasons for selection as indicator**
Frogs in emergent shoreline vegetation.	This is the only guild of frogs closely associated with the lake.
Hippos.	This red-data species is an integral component of the lake ecosystem. We have good data for this species.
Crocodiles – hatchlings and juveniles.	Hatchling and juvenile crocodiles have distinctively different habitat needs when compared with adult crocodiles. They need smaller prey items and sheltered living areas.
Crocodiles – adults.	This red-data species is an integral component of the lake ecosystem. We have good data for this species. The adult crocodiles feed mainly on larger fish. They are territorial and have very specific nest-site requirements. They are susceptible to human disturbance.

Table 7.6 List of indicators and their predicted direction of response to water level changes.

Indicator	**Definition**	**Predicted change**	**References**
Frogs	Their populations increase markedly if a linked pan habitat is available	Negative if water level is lowered	Vrdoljak & Hart 2007
Crocodile hatchlings and juveniles	Sensitive to changes in food items and nest sites	Negative if water level is lowered	Combrink *et al.* (2011a & b)
Crocodile adults	Sensitive to increasing disturbance as water levels drop	Negative if water level is lowered	Combrink *et al.* (2011a & b)
Hippos	Most susceptible to loss of grazing as groundwater levels drop	Negative if water levels are lowered	Taylor 2010

7.7.2 Description and location of indicators

7.7.2.1 Frogs:

Habitat:	Emergent shoreline vegetation.
Representative species:	*Hyperolius, Kassina,* Bufonidae
Other characteristic species:	*Afrixalus*.

Water level-related concerns: If the water level fluctuates rapidly, the shoreline vegetation will diminish. It can cope with a slow rise or fall.

The main groups of interest are the frogs associated with the emergent vegetation along the lake shoreline. These include the Bufonidae (toads), the Hyperoliidae (reed frogs and *Kassinas*) and the Ptychadenidae (grass frogs) (Du Preez and Carruthers 2009). All these frogs require water for essential parts of their life cycles and many, such as the various species of reed frogs, require emergent vegetation from which to call to attract mates. Only toads (Bufonidae) do not actually require emergent vegetation for breeding or survival from predation although they will be subject to stronger predation in the absence of a substantial amount of vegetative cover in the shallow water areas of Lake Sibaya (Poynton 1980).

Frog numbers are closely linked to other frog populations in the vicinity of the Lake. Overall frog populations are much larger when the adjacent pans are full. These shallow vegetated water bodies are ideal habitat for frogs and their tadpoles as they are warm and rich in food.

7.7.2.2 Hippos:

Habitat: Shallow water in the lake.
Representative species: *Hippopotamous amphibious*
Other characteristic species: N/A
Water level-related concerns: Should water levels fluctuate too rapidly, then shoreline vegetation will diminish providing less protection for hippos.

7.7.2.3 Adult crocodiles:

Habitat: Lake and lake margins
Representative species: Crocodilus niloticus (sub-adult and adult).
Other characteristic species: N/A.
Water level-related concerns: The beach widens as water level drops and the risks against nesting increase.

During the adult stage natural mortality is low (but they are susceptible to poaching). They require suitable food in sufficient quantities, deep water for swimming, sandbanks for basking and suitable nesting sites which will not be flooded.

7.7.2.4 Hatchlings and juvenile crocodiles:

Habitat: Shoreline emergent vegetation, vegetated part of inlets (Figure 7.16) and flooded pans in the vicinity of the lake.
Representative species: *Crocodilus niloticus* (hatchling and juvenile).

Water level-related concerns:	The main concern is to ensure that this vegetated habitat is retained in sufficient quantity for the long-term survival of crocodiles.

The hatchling stage is the period when they suffer the greatest mortality.

Figure 7.16 The distal end of an inlet showing the vegetation most important as habitat for small crocodiles

7.7.3 Linked indicators

The semi-aquatic mammal and herpetofauna indicators were linked to other indicators as shown in Table 7.7.

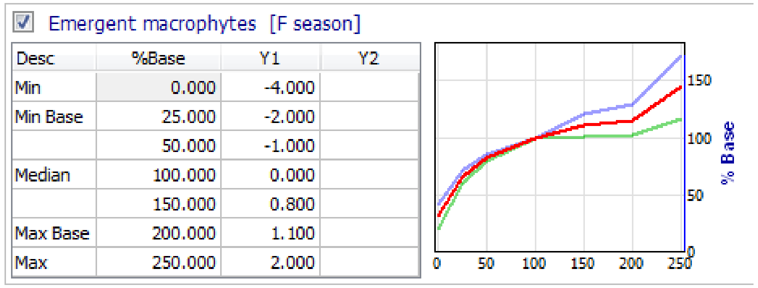
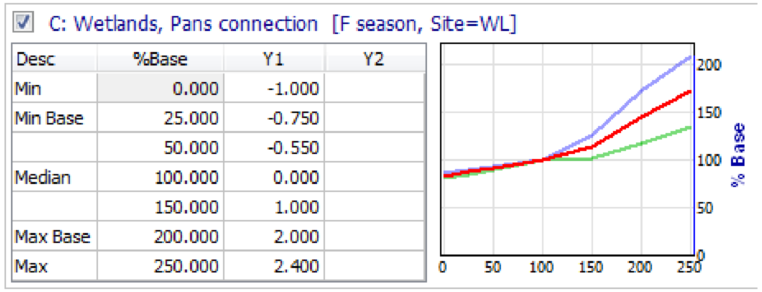
Table 7.7 Linked indicators and motivations

Indicator	Linked indicator	Motivation
Frogs	Emergent macrophytes	This is the main habitat – providing shelter.
	Connection to adjacent wetlands/pans	During wet years this expands the habitat to a large extent.
Hippos	Connection to adjacent wetlands/pans	The hippo feed in the pans – and make use of them once dry when they feed on the hygrophilous grasslands.
	Depth of daytime lie-up sites	Hippos are quite specific. They prefer lie-up sites of about 1 to 1.8 m – but will make do with shallower or deeper sites if pushed to do so. (Taylor 2013) .
	Lake water 0 to 7 m deep	This is the full range that hippos can live in. They cannot swim effectively so cannot go deeper.
	Horizontal distance to tree-line	This is an indicator of exposure to human disturbance. They prefer to have vegetation nearby.

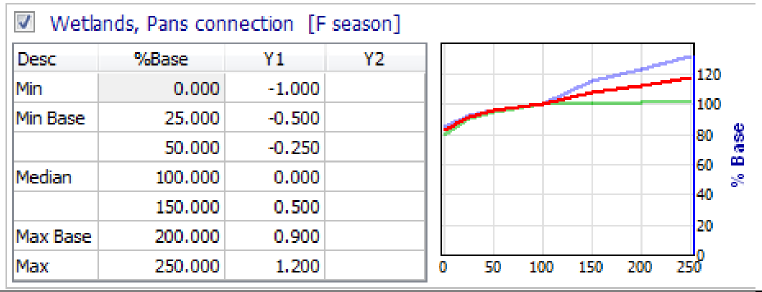
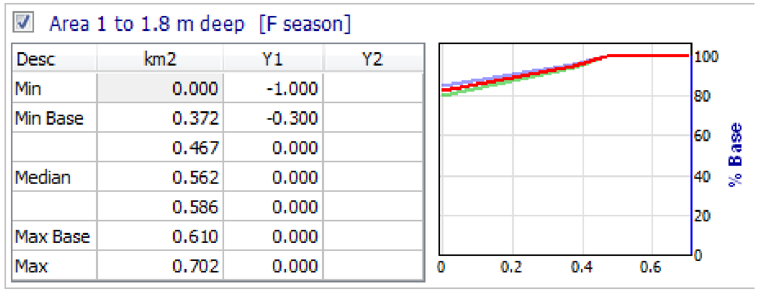
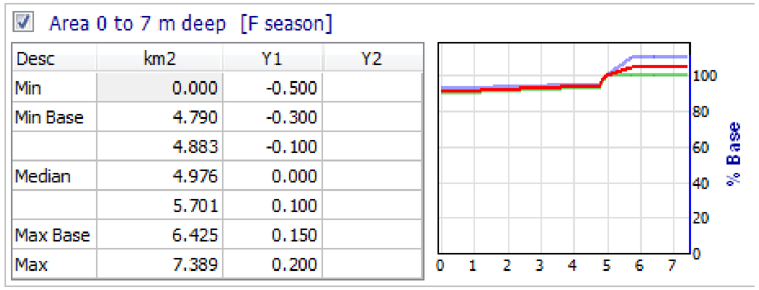
Indicator	Linked indicator	Motivation
Adult crocodiles	Mozambique tilapia	This is an important food item.
	Sharptooth catfish	This is an important food item.
	Other (not Mozambique tilapia) cichlids	If these are large enough, the crocodiles will feed on them.
	Perimeter	An indicator of habitat available.
	Horizontal distance to tree-line	This is an indicator of how exposed the nests and hatchlings are to human disturbance.
Hatchling and juvenile crocodiles	Mozambique tilapia	The young tilapias are an important food item.
	Frogs	An important food item.
	Emergent macrophytes	These provide shelter.
	Other cichlids	An important food item.
	Wetland – pan connection	This provides an extension of habitat – which is important as the pans provide good shelter from predation.
	Water 0.5 to 1 m deep	Beyond the emergent macrophytes, this is the open water that is most used by the young crocodiles.
	Potamonautes crabs	An important food item.

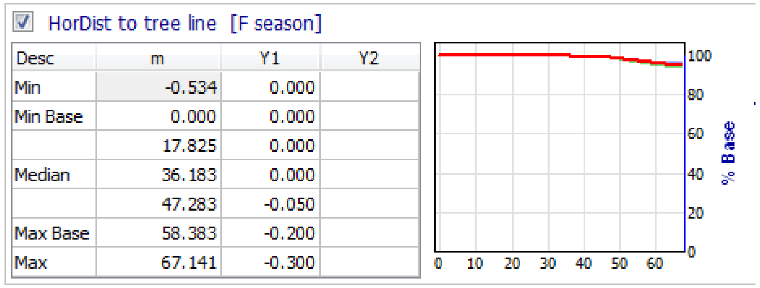
7.8 Motivations for Response Curves

7.8.1 Frogs

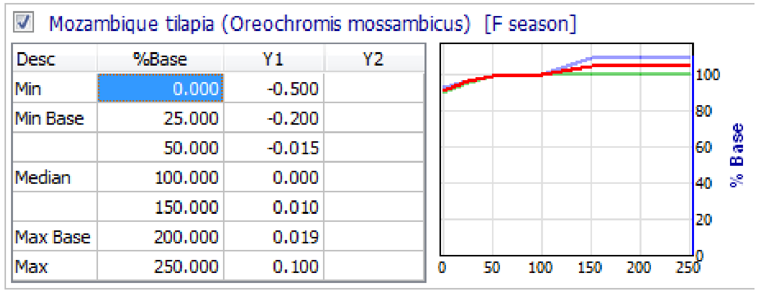
<table>
<tr><td colspan="2">Frogs.</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Emergent macrophytes [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-4.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.800</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.100</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.000</td><td></td></tr>
</table>
</td><td>The main groups of interest are the frogs associated with the emergent vegetation along the lake shoreline. These include the Bufonidae (toads), the Hyperoliidae (reed frogs and Kassinas) and the Ptychadenidae (grass frogs) (Du Preez and Carruthers 2009). All these frogs require water for essential parts of their life cycles and many, such as the various species of reed frogs, require emergent vegetation from which to call to attract mates. Only possibly the toads (Bufonidae) do not actually require emergent vegetation for breeding or survival from predation. Even the toads, however, will be much more open to predation in the absence of a substantial amount of cover in the form of vegetation in the shallow water areas of Lake Sibaya. Poynton (1980).</td><td>Moderate</td></tr>
<tr><td>
☑ C: Wetlands, Pans connection [F season, Site=WL]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.750</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.550</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.400</td><td></td></tr>
</table>
</td><td>Frog numbers are closely linked to other frog populations in the vicinity of the Lake. Overall populations are much larger when the adjacent pans are full. These shallow vegetated water bodies are ideal habitat for frogs and their tadpoles as they are warm and rich in food.</td><td>Moderate</td></tr>
</table>

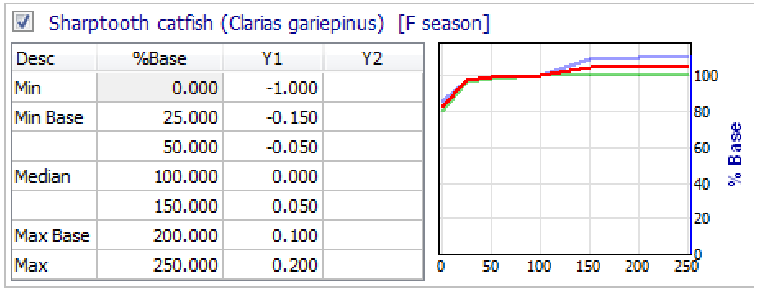
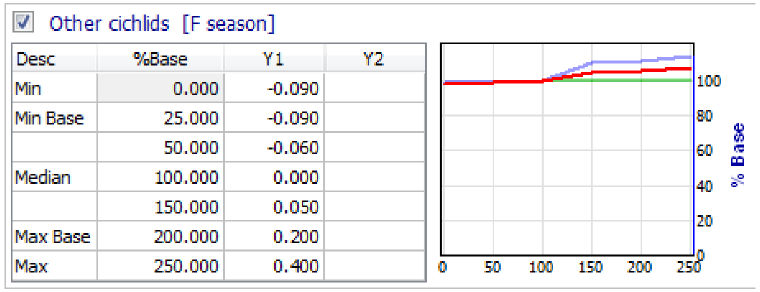
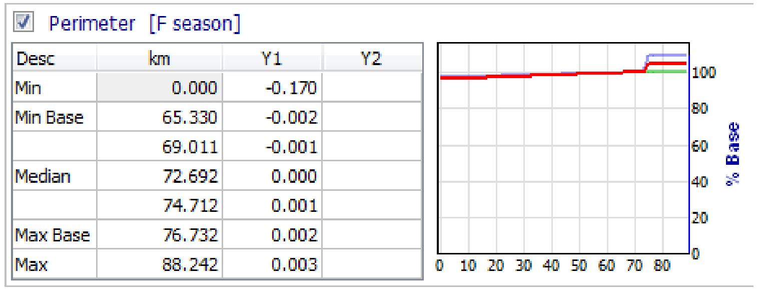
7.8.2 Hippos

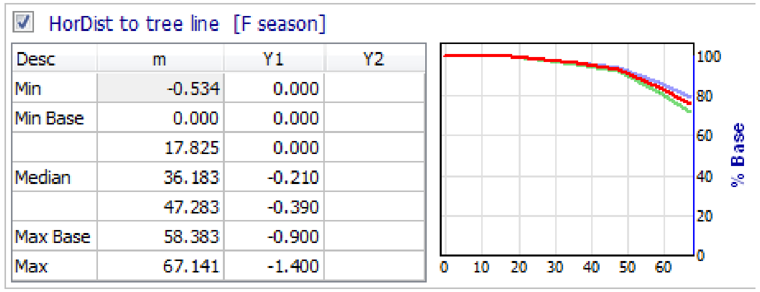
<table>
<tr><td colspan="2">Hippos.</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Wetlands, Pans connection [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.250</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.900</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.200</td><td></td></tr>
</table>
</td><td>Hippos feed a lot in pans adjacent to the lake. They also feed on the hygrophilous grassland that forms in the bottom of a pan when it dries out. If there is a lot of water some hippos will lie up in the pans to avoid the wave action in the lake. Pans may be important as sites in which the females give birth. (Taylor *pers. obs*.)</td><td>Moderate</td></tr>
<tr><td>
☑ Area 1 to 1.8 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.372</td><td>-0.300</td><td></td></tr>
<tr><td></td><td>0.467</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.562</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.586</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>0.610</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>0.702</td><td>0.000</td><td></td></tr>
</table>
</td><td>Lie up space only becomes limiting at very low levels - otherwise it is not important. If the population is very large, lie-up space may become density limiting (although this is not expected to be the case given declining numbers). (Taylor 2013)</td><td>High</td></tr>
<tr><td>
☑ Area 0 to 7 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.500</td><td></td></tr>
<tr><td>Min Base</td><td>4.790</td><td>-0.300</td><td></td></tr>
<tr><td></td><td>4.883</td><td>-0.100</td><td></td></tr>
<tr><td>Median</td><td>4.976</td><td>0.000</td><td></td></tr>
<tr><td></td><td>5.701</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>6.425</td><td>0.150</td><td></td></tr>
<tr><td>Max</td><td>7.389</td><td>0.200</td><td></td></tr>
</table>
</td><td>The maximum depth a hippo can inhabit is 7 m. It can stand on its hind legs to breathe at depths of up to 5 m - and beyond this has to push up from the bottom. Hippos have very limited ability to swim. (H Klingel, *pers. comm*.).</td><td>Low</td></tr>
</table>

<table>
<tr><td colspan="2">Hippos.</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ HorDist to tree line [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.534</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>17.825</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>36.183</td><td>0.000</td><td></td></tr>
<tr><td></td><td>47.283</td><td>-0.050</td><td></td></tr>
<tr><td>Max Base</td><td>58.383</td><td>-0.200</td><td></td></tr>
<tr><td>Max</td><td>67.141</td><td>-0.300</td><td></td></tr>
</table>
</td><td>The greater the mean beach width, the more the hippos are exposed to human disturbance when leaving the water, or when basking during the day. This makes them more prone to poaching, either as a human response to crop raiding, or for meat (Eltringham 1999).</td><td>Low</td></tr>
</table>

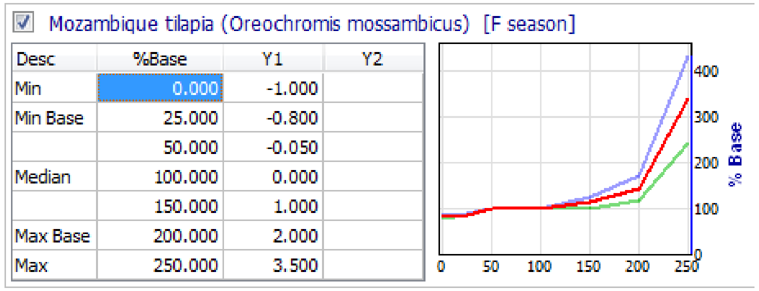
7.8.3 Adult crocodiles

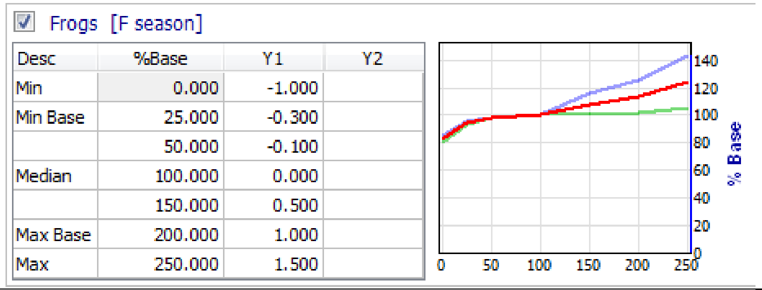
<table>
<tr><td colspan="2">Adults crocodiles</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Mozambique tilapia (Oreochromis mossambicus) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.200</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.015</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.010</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.019</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.100</td><td></td></tr>
</table>
</td><td>Mozambique tilapia are likely to be a very important prey item for large crocodiles (but not as important as *Clarias*) (Bruton 1979).</td><td>High</td></tr>
</table>

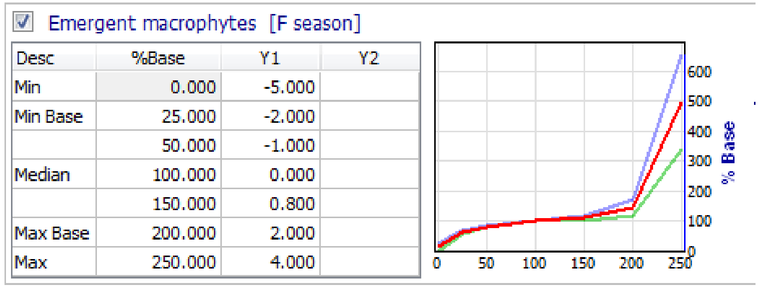
<table>
<tr><td colspan="2">Adults crocodiles</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Sharptooth catfish (Clarias gariepinus) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.150</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.050</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.050</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.100</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.200</td><td></td></tr>
</table>
</td><td>Clarias are likely to be the most important prey item for adult crocodiles in Lake Sibaya (Bruton 1979).</td><td>High</td></tr>
<tr><td>
☑ Other cichlids [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.090</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.090</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.060</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.050</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.400</td><td></td></tr>
</table>
</td><td>Prey for crocodiles - but much less important as Clarias or the Mozambique Tilapia (Weerts, pers. comm..).</td><td>Moderate</td></tr>
<tr><td>
☑ Perimeter [F season]
<table>
<tr><th>Desc</th><th>km</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.170</td><td></td></tr>
<tr><td>Min Base</td><td>65.330</td><td>-0.002</td><td></td></tr>
<tr><td></td><td>69.011</td><td>-0.001</td><td></td></tr>
<tr><td>Median</td><td>72.692</td><td>0.000</td><td></td></tr>
<tr><td></td><td>74.712</td><td>0.001</td><td></td></tr>
<tr><td>Max Base</td><td>76.732</td><td>0.002</td><td></td></tr>
<tr><td>Max</td><td>88.242</td><td>0.003</td><td></td></tr>
</table>
</td><td>The greater the area of lake perimeter, the more space available for crocodiles. This may be important when the population numbers are very high (but is unlikely to be the case given declining numbers).</td><td>Moderate</td></tr>
</table>

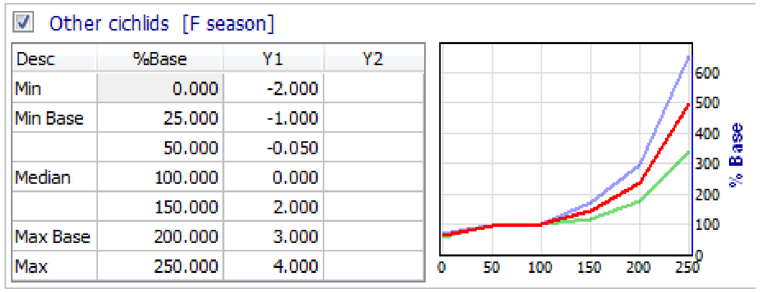
<table>
<tr><td colspan="2">Adults crocodiles</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ HorDist to tree line [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.534</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>17.825</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>36.183</td><td>-0.210</td><td></td></tr>
<tr><td></td><td>47.283</td><td>-0.390</td><td></td></tr>
<tr><td>Max Base</td><td>58.383</td><td>-0.900</td><td></td></tr>
<tr><td>Max</td><td>67.141</td><td>-1.400</td><td></td></tr>
</table>
</td><td>This indicator describes the distance the crocodiles have to move to their nests - and how far the hatchlings need to be carried from the nest. The further the distance the greater the risk of predation or mortality from heat stress on hatchlings (Kyle, <i>pers. comm.</i>.).</td><td>High</td></tr>
</table>

7.8.4 Hatchling and juvenile crocodiles

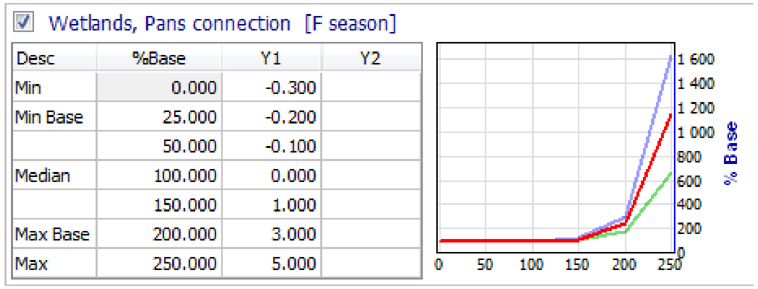
<table>
<tr><td colspan="2">Hatchlings and juvenile crocodiles:</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Mozambique tilapia (Oreochromis mossambicus) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.800</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.050</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.500</td><td></td></tr>
</table>
</td><td>Juveniles of tilapia are important prey items for young crocodiles (Pooley 1962).</td><td>High</td></tr>
</table>

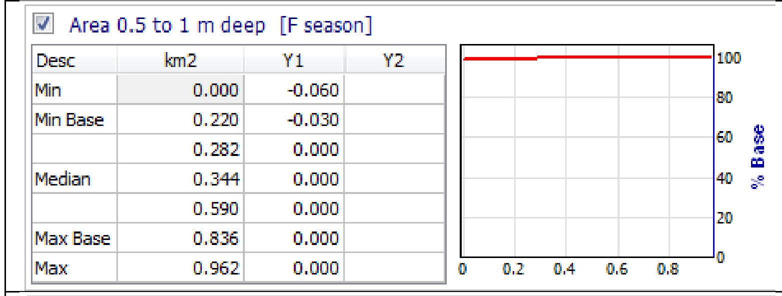
<table>
<tr><td colspan="2">Hatchlings and juvenile crocodiles:</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Frogs [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.300</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.100</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.500</td><td></td></tr>
</table>

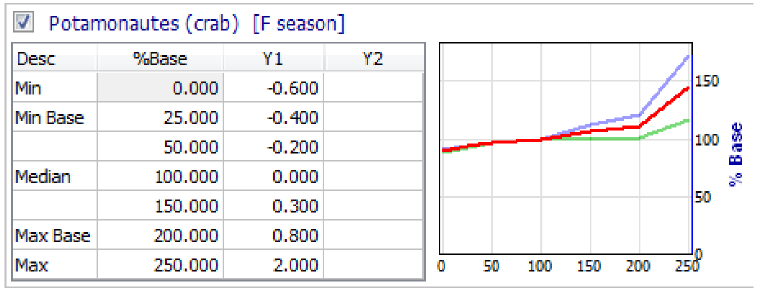
</td><td>Frogs are fed on by crocodile hatchlings (Bruton 1979).</td><td>Low</td></tr>
<tr><td>

☑ Emergent macrophytes [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.800</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>4.000</td><td></td></tr>
</table>

</td><td>Emergent macrophyte vegetation provides shelter for hatchlings and juveniles.</td><td>High</td></tr>
<tr><td>

☑ Other cichlids [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.050</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>3.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>4.000</td><td></td></tr>
</table>

</td><td>Cichlids are prey items for juvenile crocodiles (Pooley 1962).</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Hatchlings and juvenile crocodiles:</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Wetlands, Pans connection [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.300</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.200</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.100</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>3.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>5.000</td><td></td></tr>
</table>

</td><td>Wetlands, pans and inlets are important habitats for young crocodiles, and availability of such habitat is possibly the single most important feature affecting their survival.</td><td>Moderate</td></tr>
<tr><td>

☑ Area 0.5 to 1 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.060</td><td></td></tr>
<tr><td>Min Base</td><td>0.220</td><td>-0.030</td><td></td></tr>
<tr><td></td><td>0.282</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.344</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.590</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>0.836</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>0.962</td><td>0.000</td><td></td></tr>
</table>

</td><td>Water depths of 0.5-1m is the dominant water habitat for hatchling and juvenile crocodiles.</td><td>Moderate</td></tr>
<tr><td>

☑ Potamonautes (crab) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.600</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.400</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.800</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.000</td><td></td></tr>
</table>

</td><td>Potamonaute crabs are a key food item for juvenile crocodiles. (Bruton 1979).</td><td>Low</td></tr>
</table>

7.9 Assumptions and limitations

- For Lake Sibaya there is a good history of crocodile and hippo censuses (mainly aerial surveys from aircraft) which provide data on the population status of these species. In addition there have been nest surveys to determine crocodile nesting success. For both species, EKZNW maintains records of deaths, and the cause of deaths, but these mortality data are limited and expected to be irregular.
- A key limitation is that census methods and observers have changed over the years and this may lead to some degree of uncertainty in the accuracy and comparability of the count data from year to year.
- There is little known about where hippos feed exactly in Lake Sibaya so their ranges and other habitat preferences have been extrapolated from data on hippos in Lake St Lucia.
- For crocodiles there are enormous differences in the characteristics of this species that vary according to the area, climate, food availability, food suitability, pollution and other factors.
- For frogs and reptiles (other than crocodiles) and mammals (other than hippos), the study has had to rely on the checklists provided by Bruton (1980) and lists in the Frog Atlas (Minter *et al.*2004) and the Reptile Atlas (Bates *et al.*2014). It has been assumed that the species associated with water have the same biological and life-history characteristics as those recorded in the literature.

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8 BIRDS

Note: This specialist report is incomplete and will be completed on receipt of input from the specialist.

8.1 Introduction

This Section comprises the summary specialist report for the birds, and provides:

- An overview of the study area, with focus on delineation of homogenous bird areas;
- For the EWR zones:
    - EcoClassification assessments for the birds, with supporting evidence;
    - the DRIFT indicators chosen, and reasons for selection;
    - the relationships between the selected indicators and water level or other drivers for inclusion in the DRIFT DSS, with referenced, supporting motivations.
- EcoSpecs and monitoring actions required to describe and monitor the recommended Ecological Status with respect to the birds.

8.2 Description of the study area, with the focus on birds

Lake Sibaya is a unique, endorheic lacustrine freshwater ecosystem within the Maputaland coastal plain (Figure 8.1). The area has a strong rainfall gradient that increases towards the coast, with average rainfall varying from about 700 mm on the west of the lake to about 1200 mm at its eastern margin. Accordingly, the surrounding natural vegetation varies from dense coastal forest to woodland in the west. The area is well known for its wildlife, and especially its birds, with more than 279 species of birds having been recorded at the lake alone. At least 65 of these are water-associated species. The lake falls within the iSimangaliso Wetland Park, a World Heritage Site, and is listed as a wetland of international importance under the Ramsar Convention. Human settlement are scattered around the area, particularly in the west, and has led to increasing expansion of human activities and disturbances on wildlife, including birds.

Lake Sibaya is an important habitat for waterbird species that are resident in the region as well as for species that utilise the area on a seasonal or opportunistic basis for breeding or feeding. It is understood to function as a refuge for certain waterbirds during the dry season, when many of the shallower pans and wetlands in the region are dry.

Figure 8.1 Aerial view of Lake Sibaya main basin, looking south-east towards the Southern Basin in the distance (wetu.com)

The 7750 ha lake, originally connected to the sea, is separated from the sea by forested coastal dunes. The lake has over 100 km of largely untouched shoreline, undulating around its fringing peripheral sheltered bays and exposed and reed-fringed shores. Within the lake, there are shallow terraces that drop off steeply into the main lake area which reaches depths up to 40 m (Figure 8.2). The sheltered bays extend from the lake along drainage lines that enter the lake, and these areas are characterised by marsh habitat and backwaters supporting floating vegetation and waterlilies. The surrounding areas, vegetated with forest and woodlands, are mostly set back some distance from the water, but are close to the water’s edge in some places.

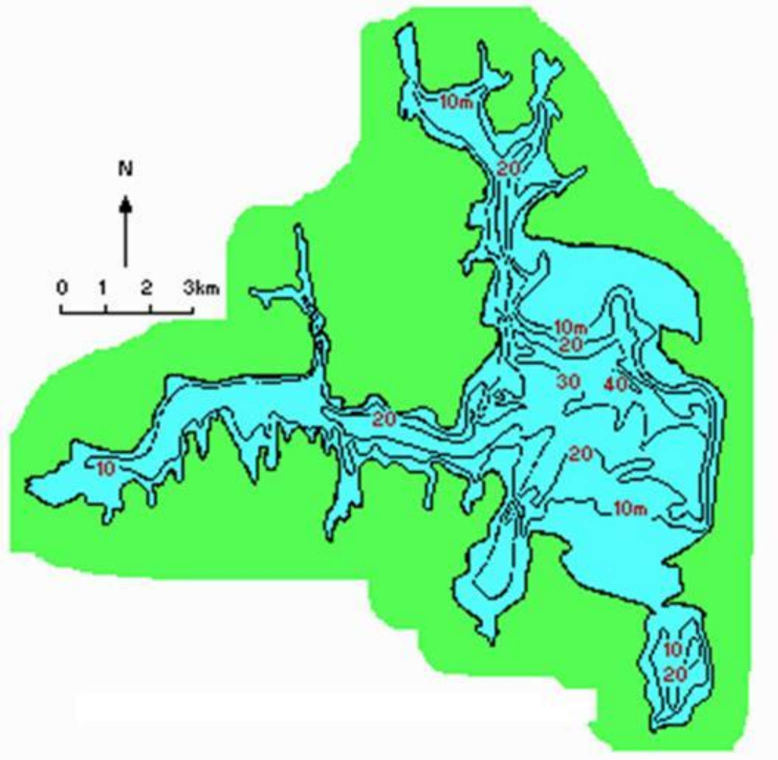

Figure 8.2 Bathymetric map of Lake Sibaya showing the main lake and peripheral ‘arms’ with their sheltered bays (Hill 1979)

The lake is described as being on the boundary between an oligotrophic or mesotrophic system. It has relatively low levels of nutrients and productivity, with a relatively low biomass of invertebrates and fish. Productivity is concentrated in the peripheral wetlands and sheltered bays, where there is an abundance of rooted and floating macrophytes, invertebrates, amphibians, and small fish, all of which support an abundant birdlife (Figure 8.3).

Figure 8.3 Marshes in the western arm (Panoramio.com)

The shallow, sandy littoral margins support a relatively high level of phytoplankton productivity compared to deeper parts of the lake but do not support much in the way of rooted macrophytes or fish. These areas vary in attractiveness to fish and birds as lake levels vary, but may offer habitat for wading birds. Macrophytes are reportedly more abundant on the slopes below the terraces, where higher biomass of fish – a primary food source for many wetland birds, such as herons - is also found (Figure 8.4). Below this zone, the deep parts of the lake are well oxygenated and support a reasonable biomass of invertebrates and fish.

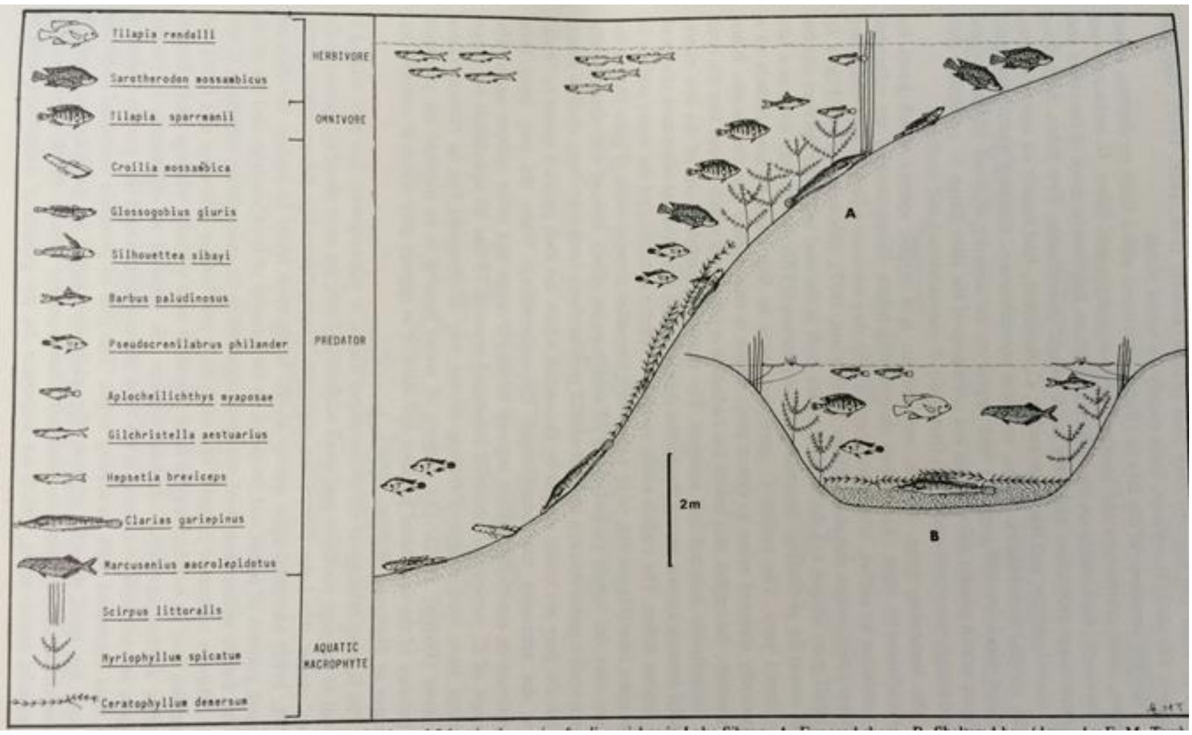

Figure 8.4 Schematic diagram of fish distribution in Lake Sibaya (Bruton 1980)

While there is no intertidal area, wind creates patches of exposed shore in different parts, providing a habitat for certain waders. Around parts of the lake, sandy beach and dune areas provide suitable feeding and breeding habitat for waders.

While there is only very minor seasonal variation in lake levels, the water levels vary over long (in the order of decades) cycles, with a long-term variation of about 3.5 m. The low levels recorded over the last few years are unprecedented in the last 100 years. Lake levels were relatively high from the mid 1970s until the early 1990s compared with the periods before and after (Figure 8.5).

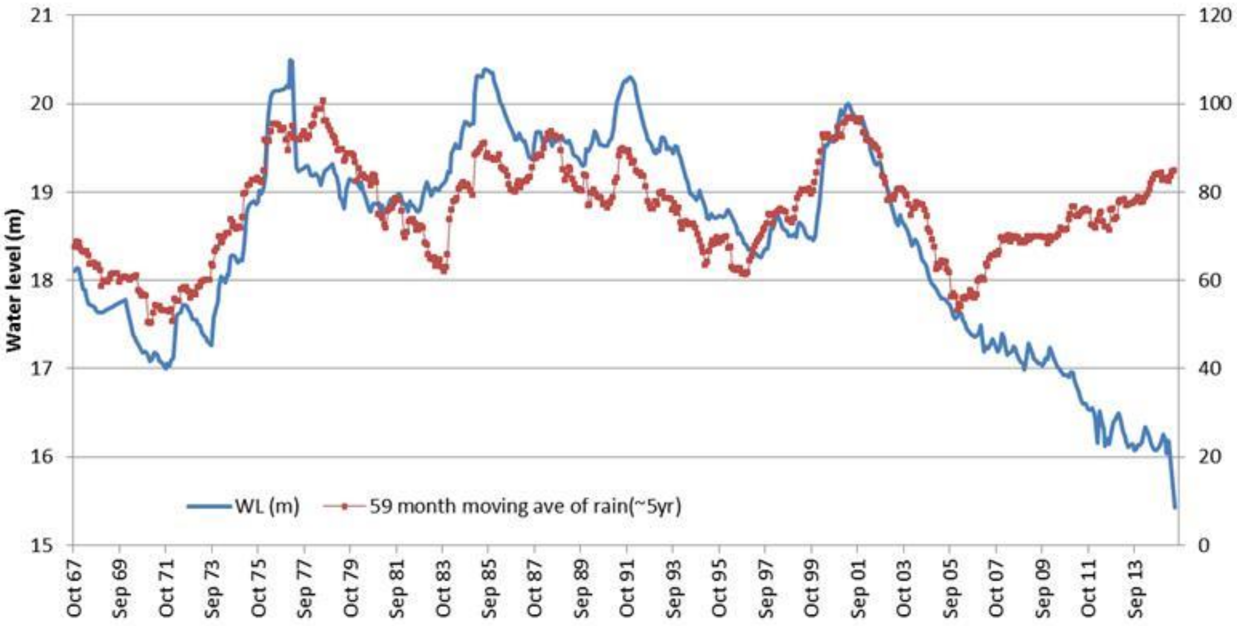

Figure 8.5 **Variation in rainfall and lake water level from 1967 to present**

8.3 Available data on waterbirds

The following data on waterbirds at the lake were used in this study:

- Counts of the top 15 species for 1970 and 1976 (Bruton 1979)
- Bird checklist by Cyrus *et al*. (1980)
- Brief description by Bruton (1980)
- Phil Hockey count Dec 1981 (Ryan *et al*. 1988)
- Summer and winter Coordinated Waterbird Counts (CWAC) counts 1992-2014
- Field notes (R Taylor) July 2015.

Of the above, the main data source was the CWAC count information. These counts were undertaken regularly over two periods (shown in red on Figure 8.6). There were no data on the distribution of birds in different parts of the lake (ie EWR zones) apart from notes made during the field visit for this study.

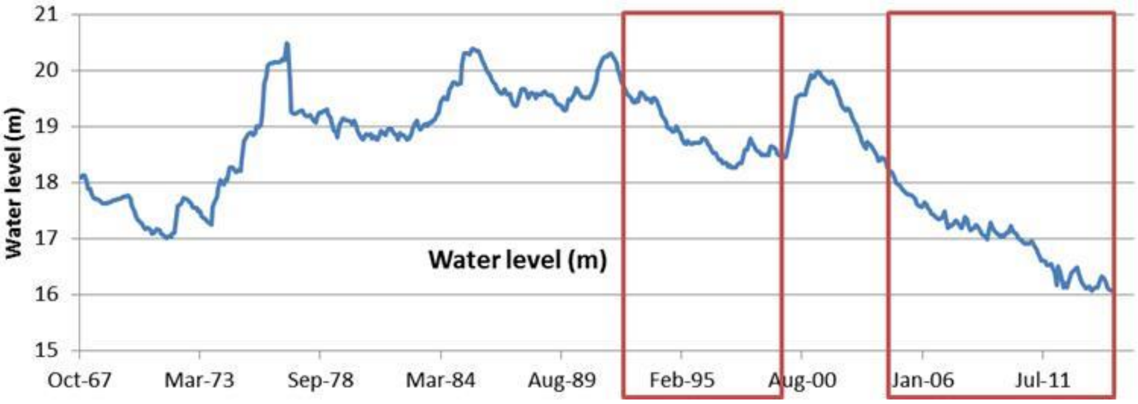

Figure 8.6 Periods for which CWAC count data were available, in relation to water level changes

8.4 Analysis of available data

8.4.1 Species richness and abundance of main groups

A total of 70 non-passerine waterbird species have been recorded in counts at Lake Sibaya. However since birds move from different parts of the lake with high frequency, the actual numbers of species recorded at any particular moment in time is generally less than half of this. An average of 33 species has been recorded in summer counts, and 32 species in winter counts. This does not include rare species such as Pel's Fishing Owl and Rufousbellied Heron which have also been recorded by birdwatchers in the area.

The total number of birds recorded at Lake Sibaya in counts since 1970 has ranged from 402 to 1923. Counts in recent years (since 2005) have been significantly higher than in previous years (Figure 8.7).

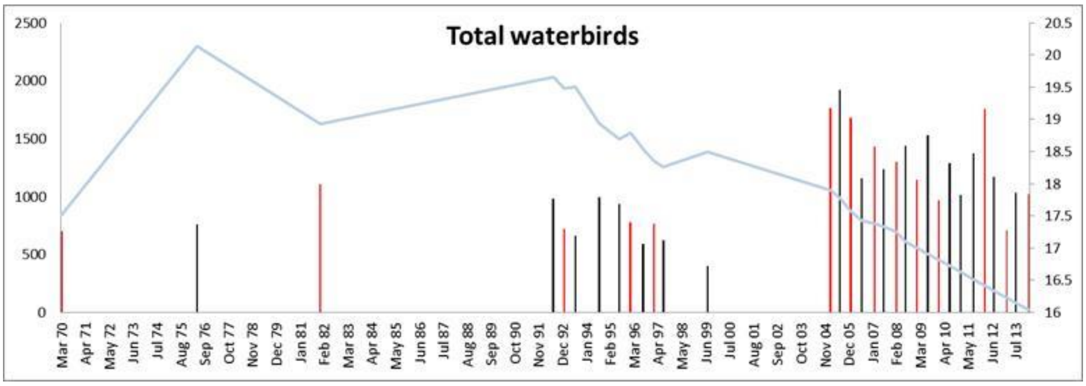

Figure 8.7 The total number of birds recorded in all known counts of Lake Sibaya from 1970 to 2014. Water levels in the month of counting are shown for reference (though note that the water levels in between counts are not plotted). Summer counts are marked in red.

There is very little seasonal variation in total numbers, with a summer average of 1159 and a winter average of 1090. However, the composition of birds does change seasonally (Figure 8.8). Cormorants and darters are resident at Lake Sibaya, where they breed colonially. As a result there is little seasonal variation in this group. Most of the wading birds species are also resident, but there are summer influxes of certain species, such as Cattle Egret. Waterfowl numbers increase in winter, during the dry season, probably as a result of movements into the wetland as availability of water decreases in the region. The numbers of waders are higher in summer as a result of the use of the area by Palearctic-breeding summer migrants. Numbers of gulls and terns, birds of prey and kingfishers tend not to vary seasonally as most of these birds remain resident in the area.

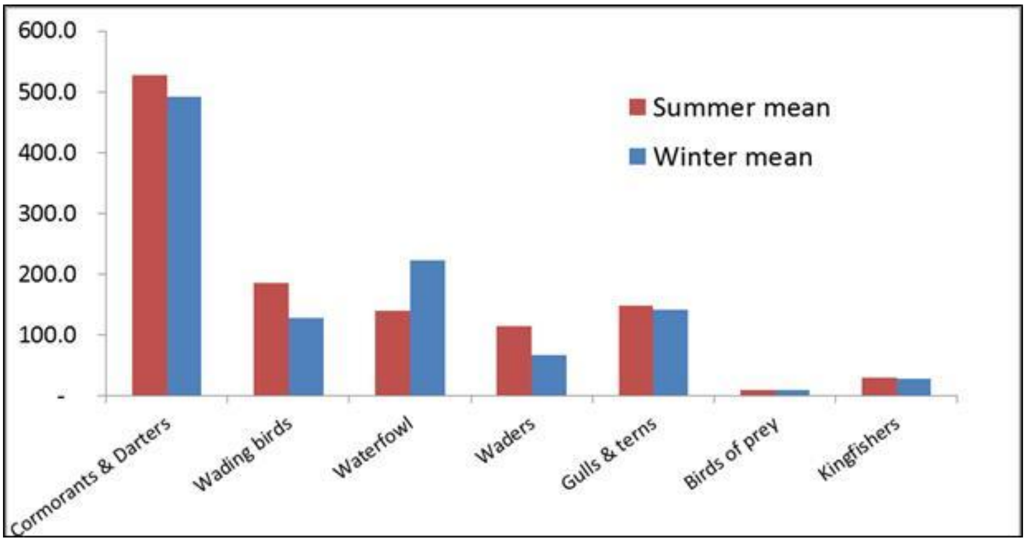

Figure 8.8 **Average numbers of birds in seven taxonomic groupings during summer and winter CWAC counts**

Numbers of birds were also compared for the two CWAC counting periods during which water levels were relatively high and low, respectively. The numbers of wading birds, waterfowl, waders, gulls and terns were all significantly higher in the second period than in the first (Figure 8.9). These are all groups in which a large proportion of species utilise marginal habitats, such as shallow areas and exposed shores.

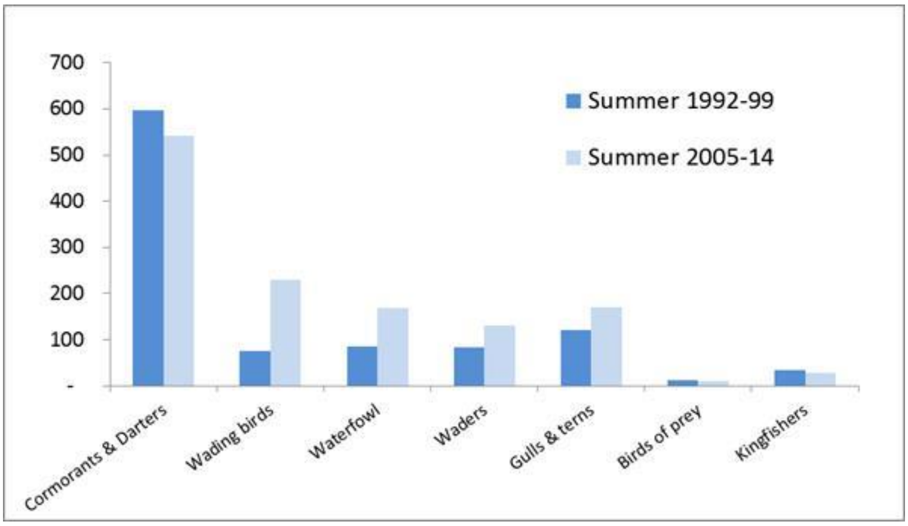

Figure 8.9 **Average numbers of birds in seven taxonomic groupings during summer counts of 1992-99 (high water levels) and 2005-14 (low water levels)**

The once-off count in 1981 was quite different from the later CWAC counts, even though water levels were in the same range as the first set of counts (Figure 8.10). High numbers of darters were recorded, but this appears to have been due to misidentification or mis-recording as the total numbers for the cormorant group were in the expected range. A very high number of white-winged terns were recorded, resulting in a very high total for that group. However numbers of all the other groups were very much lower. These apparently anomalous results may be due to the fact that this count was done by a single counter from the shore, whereas the CWAC counts are done by boat by more than one person, and probably cover more of the backwater areas around the lake.

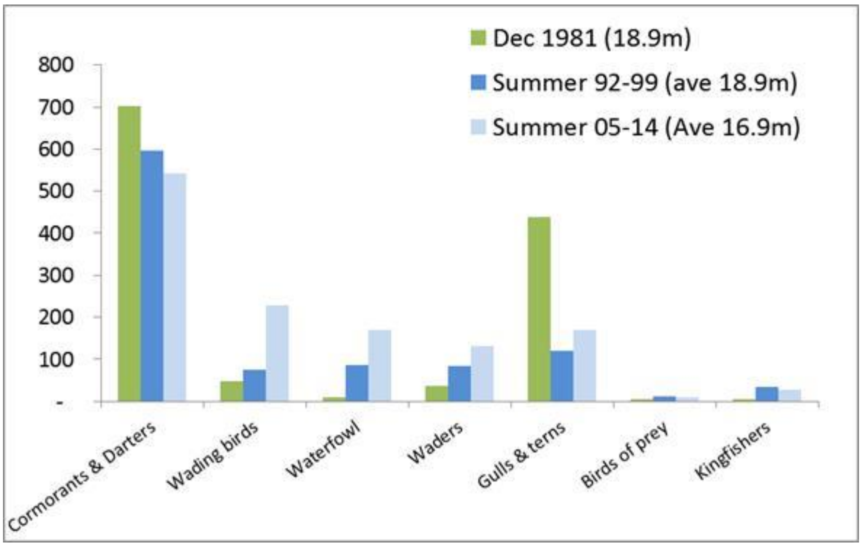

Figure 8.10 **The December 1981 count compated to the later CWAC counts**

8.4.2 Distribution of birds on the lake

No count data were available on the distribution of birds in different parts of the lake. Field observations during very low water levels in 2015 (Table 8.1) suggested that most birds were concentrated in the Western Arm (Figure 1.2), which was acting as a refuge under the prevailing conditions. This area is nutrient-enriched. In general, waders and waterfowl characteristic of marsh areas as well as egrets and ibis characteristic of disturbed landscapes were more prevalent in the Northern and Western Arms and the Southwestern basin. Species characteristic of calm backwater areas with emergent and floating macrophytes such as African Jacana, Yellow-billed Duck and Purple Heron, were most common in the Southwestern and Southern Basins. Cormorants tended to be seen in the eastern parts of the lake, particularly the Southern Basin, where they breed colonially (in Swamp Fig trees, now dead) and the Main Basin. Waders that are characteristic of open sandy shores are concentrated in the Main and Southern Basins. The freshwater/lake terns (White-winged and Whiskered Terns) occur in any expansive open water areas.

Table 8.1 Field observations during July 2015 (only the Western Arm was counted, R Taylor)

	Western Arm	**Northern Arm**	**Southwestern Basin**	**Main Basin**	**Southern Basin**
Dabchick	6	x	X		X
White-breasted cormorant				X	X
Reed cormorant		x			X
Purple heron			X		
Cattle egret	60				
Hadeda	5				
Glossy ibis	15				
Hamerkop			X		
Fish eagle		x			
Yellow-billed duck	20		X		
Egyptian goose	10		X	X	X
Redbill teal	30				
Moorhen		x			
Purple gallinule		x			
African jacana	10	x	X		
Stilt	10			X	X
3-banded plover	1			x	
Blacksmith plover	2				
White winged black tern ?		x		X	
Whiskered tern (?)	30		X		
Pied king fisher					
Cape wagtail					X

Bruton (1979) described the avifauna in the period from 1970 to 1976. His description was fairly similar to the situation observed in recent years:

- The avifauna was dominated by Reed & Whitebreasted Cormorants.
- Other common species included three species of kingfishers, African Fish Eagles (7prs), several large herons, African Darter and Greyheaded Gull.
- The area was an important breeding area for Whitefronted Plover, and supported few other waders.
- The sheltered bays had a distinctive fauna characterised by African Jacana, Black Crake, African Purple Gallinule and Common Moorhen.
- Little Grebe (=Dabchick) was the most common species found in open water areas.

8.4.3 Responses of different bird groups to changes in water level

8.4.3.1 Little Grebe

Little Grebe feed on small fish and invertebrates by diving in relatively deep open water, and also shelter near emergent vegetation. Studies of habitat use suggest that Little Grebe prefers shallow water habitats with preponderance of reed vegetation, slightly high alkalinity, low water temperature and low turbidity (Bilal *et al.* 2013). This species uses emergent reed marsh for shelter and nesting sites, open water for foraging on small pelagic fish and invertebrates, and also forages among submerged macrophytes. It has been recorded from a wide range of depths, but usually in wetlands with water deeper than 0.3 - 0.4 m and with rich vegetation (Fieldsa 2004, Ceccobelli & Battisti 2010; Bilal *et al.* 2013). In shallow wetlands, densities of Little Grebe are positively correlated with maximum water depth in channels, but in wetlands with variable water depths, they avoid diving in areas too deep (>1 m) because of the energetic costs (Ceccobelli & Battisti 2010). Numbers of this species at Lake Sibaya were highly variable, but do not appear to be influenced by changes in water level. Many birds are likely to move away from the lake to find suitable places to breed during the rainy season.

8.4.3.2 Cormorants

White-breasted and Reed Cormorants breed and roost on marginal trees and feed by swimming in fast pursuit of small to medium-sized fish which they catch with a hooked bill. Studies of Reed Cormorants in Lake Kariba suggest that they dive to an average depth of about 2 m (Birkhead 1978). At Lake St Lucia, Reed Cormorants foraged on small fish (mainly 3-4g) in shallow water of 30 cm to 2 m depth within 100 m of the shore (Whitfield & Blaber 1979). Whitebreasted Cormorant fished in deeper water, usually between 10 m and 200 m from the shore, but up to 1 km, and fed on larger fish (mainly 10-20g; Whitfield & Blaber 1979). In Lake Kariba, Reed Cormorant numbers have been shown to be related to fish abundance (Junor *et al.* 1987).

At Lake Sibaya, numbers of cormorants do not appear to be correlated with water level. Numbers increased dramatically from the 1990s to the mid-2000s, then started to decrease again as lake levels declined (Figure 8.11). One possible reason for this pattern is an influx of birds from surrounding areas as a result of drought and the drying of more seasonal wetlands and streams elsewhere. Lake St Lucia, for example, experienced extremely low water levels during the early to mid-2000s.

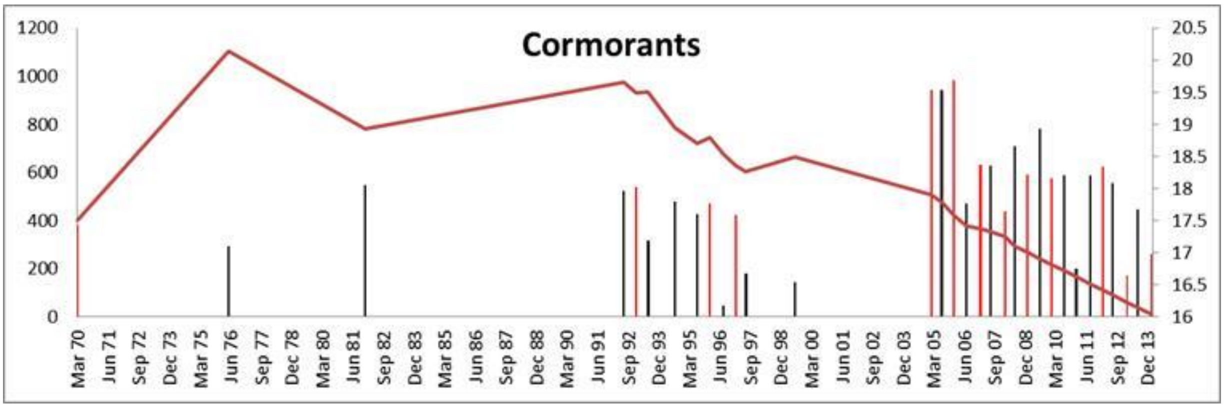

Figure 8.11 Counts of cormorant s from 1970 to 2014 (summer = red). Water levels at count dates are plotted for reference

8.4.3.3 Darters

Darters have a very similar foraging behavior and diet to cormorants. However, while cormorants have hooked bills with which to catch fish, darters use their spear-like beaks to impale their prey. In Lake Kariba, both Reed Cormorant and Darter fed in the littoral areas of the lake at a mean depth of about 2 m, and cichlids represented over 90% by numbers and over 70% by weight of their diets (Birkhead 1978). There appeared to be no obvious ecological isolation between the two species, although Darters tended to take a wider variety of prey species (Birkhead 1978). However subsequent research suggests that Darters are neutrally buoyant at 2 - 4 m, whereas Reed Cormorants are neutrally buoyant at 5-6 m (Hustler 1992). At Lake Sibaya, however, unlike Reed Cormorant, African Darter was seldom recorded at lake levels lower than 17.5 m, and above this level, their numbers were positively correlated with water level (Figure 8.12).

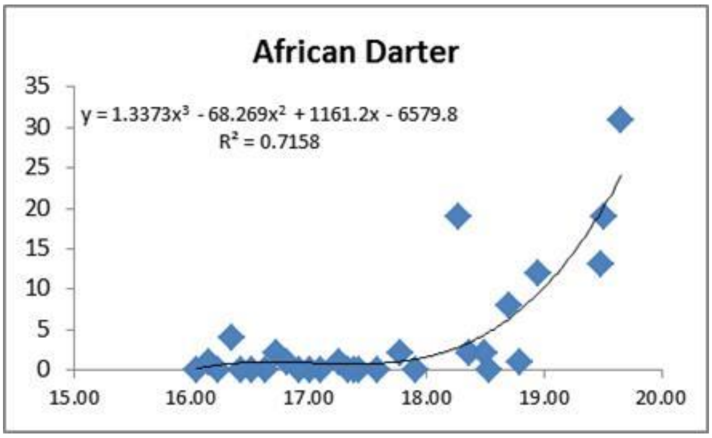

Figure 8.12 Relationship of darter numbers to water level

8.4.3.4 Wading birds

Wading birds are the herons, egrets, ibises and spoonbills that feed by wading in water depths up to about 20 – 30 cm. Herons and egrets wade in search of fish and amphibians which they catch by stealth hunting or through cooperative behaviour. Spoonbill feed on fish and invertebrates by dabbling at the mud surface, and ibises feed by probing in the mud for invertebrates.

This group at Lake Sibaya is dominated by Little Egret. Cattle Egret were counted in higher numbers, and have increased with decreasing water levels (see also discussion on Blacksmith Lapwing), but were not included as a waterbird. Other commonly-recorded species are the Purple, Grey and Goliath Herons, and to a lesser extent, the Great Egret and Squacco Heron. Other species such as Dwarf and Little Bittern have also been recorded at the study area, but because of their secretive habits, the count data do not give an indication of their abundance.

Although different species respond differently to water level, herons and egrets were generally most abundant at intermediate water levels (Figure 8.13). This was particularly true for Little Egret and Goliath Heron. Grey Heron and Purple Heron were more abundant at both intermediate and lower water levels. Squacco Heron numbers were the exception in that their numbers were positively correlated with water level.

The patterns observed were probably a function of two opposing factors. On the one hand the prey of these species becomes more concentrated and easier to catch at lower levels, whereas on the other hand, the emergent reed marsh that they favour for roosting and breeding, and in some cases, for foraging, increases with increasing water level. Thus as long as reed marsh becomes scarce at low water levels and prey availability is reduced at high water levels (especially if the increase in water level has been rapid), it might be expected that conditions are optimal at intermediate water levels.

Of the ibis and spoonbills, only African Sacred Ibis numbers were related to water level. Numbers increased with water level above a threshold of about 17 m (Figure 8.14). Storks occur regularly but in very low numbers. Saddle-billed Stork were only recorded when lake levels were below about 18 m. This may be due to the drying up of suitable habitats elsewhere, as well as the availability of suitable water depths in which to forage by wading. Greater Flamingo has only been recorded at the lake at very low water levels (below 16.3 m).

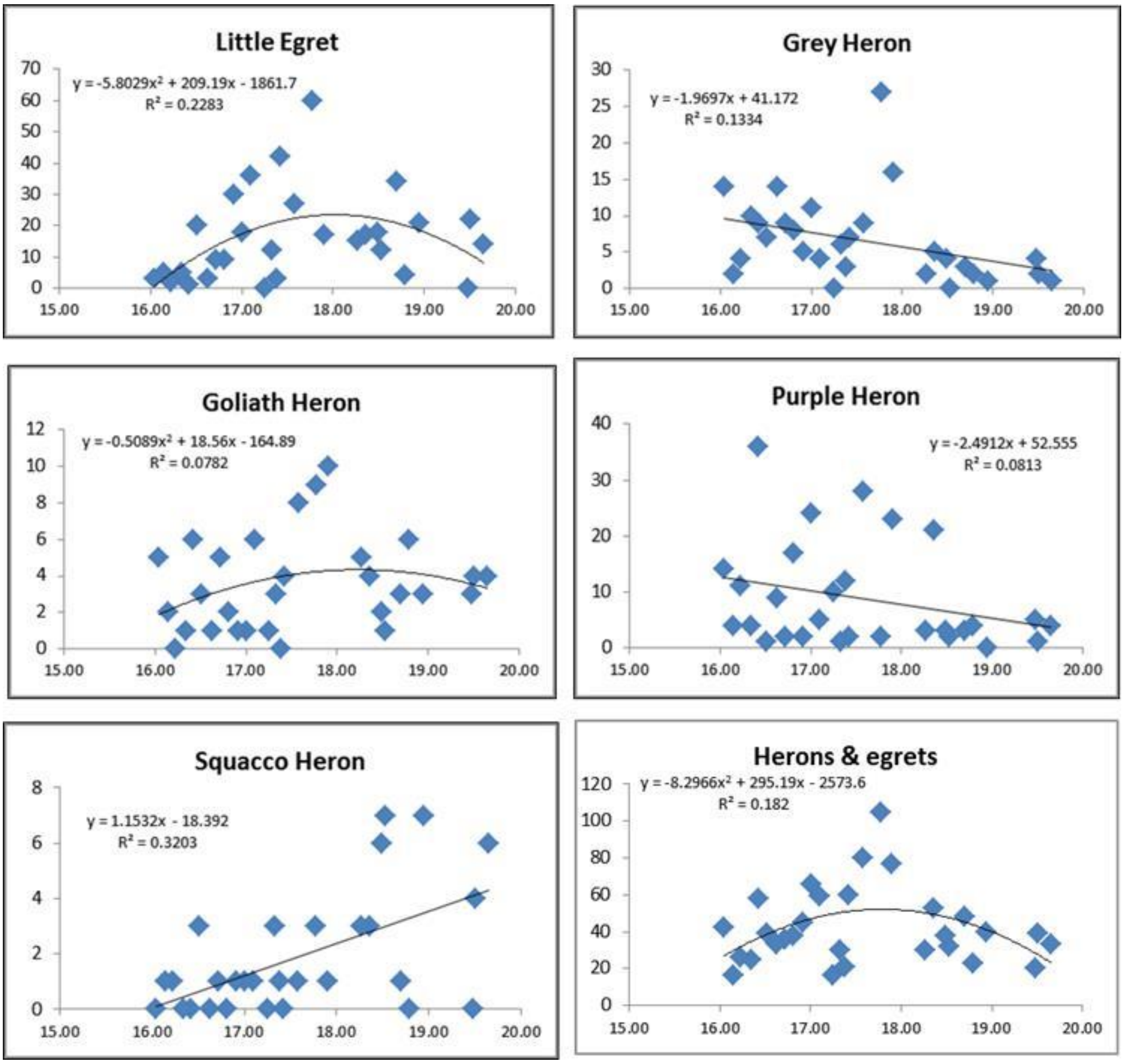

Figure 8.13 Relationship of heron and egret numbers to water level

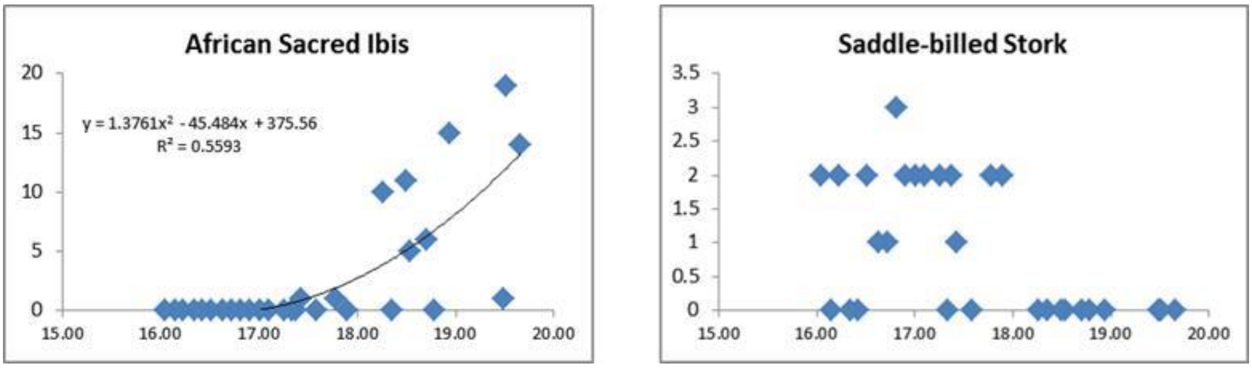

Figure 8.14 Relationships of ibis and stork numbers to water level

8.4.3.5 Waterfowl

Waterfowl on the lake (other than grebes) are dominated by Egyptian Goose and Yellow-billed Duck. Other regularly-recorded species include Spur-winged Goose, White-faced Duck, Red-billed Teal and African Pygmy Goose. There are occasional records of Comb Duck, Fulvous Duck and White-backed Duck.

Spurwinged and Egyptian Goose have both increased in relation to decreasing water level (Figure 8.15). This could be related to increasing availability of loafing habitat, but may be driven to some extent by regional increases in their populations. Yellow-billed duck are uncommon at water levels above 18 m. This is less likely to be due to loss of suitable habitat, and more likely to be due to the fact that they have spread out to other wetlands that become suitable during high rainfall periods. Species such as Yellow-billed Duck and Red-billed Teal are highly mobile in response to changes in habitat availability. Thus the waterfowl species that increase with decreasing water level are probably doing so largely in relation to decreasing availability of suitable habitat elsewhere.

Conversely, African Pygmy Goose is rarely recorded when the lake is below 18 m, and above this threshold is positively influenced by water level. Numbers of White-faced Duck are positively correlated with water level. African Pygmy Goose feeds mainly on the plants and seeds of the waterlily Nymphaea. It also has a clear preference for tree-hole nesting, which means that it requires woodland habitat for breeding. While woodland habitat around the lake has been impacted by increasing human populations and collection of firewood, the loss of this species is probably more directly tied to a loss of backwater areas. White-faced Duck eat underwater tubers and seeds of aquatic plants, have similar habitat requirements. The decrease of White-faced Duck with decreasing water level is likely to be related to reduction in suitable habitat.

The rallid waterfowl, mainly represented by Common Moorhen, African Purple Swamphen and Black Crake, are more difficult to count accurately. No significant relationships to water level were found, but it is likely that these species are favoured by increasing water level and availability of dense emergent marsh.

8.4.3.6 Birds of prey

About 7 to 10 pairs of African Fish Eagle have been resident on the lake for as long as counts have been carried out. In addition, African Marsh Harrier and Osprey are recorded occasionally. All the birds are not recorded on every count, so counts vary, but the numbers of African Fish Eagle observed have apparently declined in relation to water level (Figure 8.16). Whether they have abandoned the area or have been increasingly using other fishing grounds is unclear.

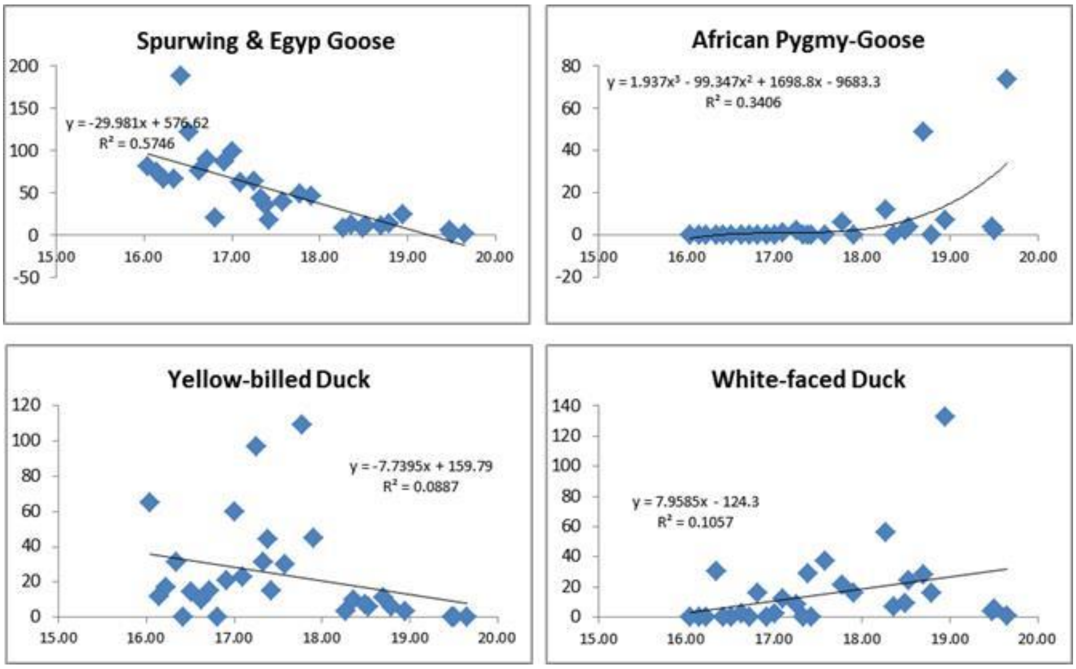

Figure 8.15 Relationships of anatid waterfowl numbers to water level

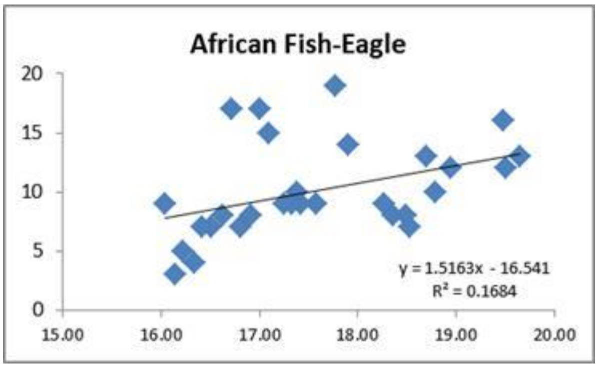

Figure 8.16 Relationships of African Fish Eagle numbers to water level

8.4.3.7 *Waders*

A total of 17 wader species have been recorded on the lake. These include: (i) waders that are commonly found on exposed or very shallow sand/mud banks, which are dominated by White-fronted Plover (which breeds at the lake), and the migrant Common Greenshank and Common Sandpiper, and (ii) those that are more typically found in backwater areas, marshes and flooded grassland, which are dominated by African Jacana and Black-winged Stilt. Blacksmith Lapwing occurs in the grassland areas around the lake.

There is a strongly negative relationship between White-fronted Plover numbers and water level, because the amount of beach available to birds increases as the lake levels drop (Figure 8.17). There is clearly very little beach habitat above 17.5 m. Conversely, African Jacana numbers (variable because they are a relatively shy species) increase slightly at higher water levels. Numbers of Blacksmith Lapwing have also increased as lake levels have dropped, but this may be due to increased short grass habitat as cattle have moved into the area as a result of reduced availability of water elsewhere.

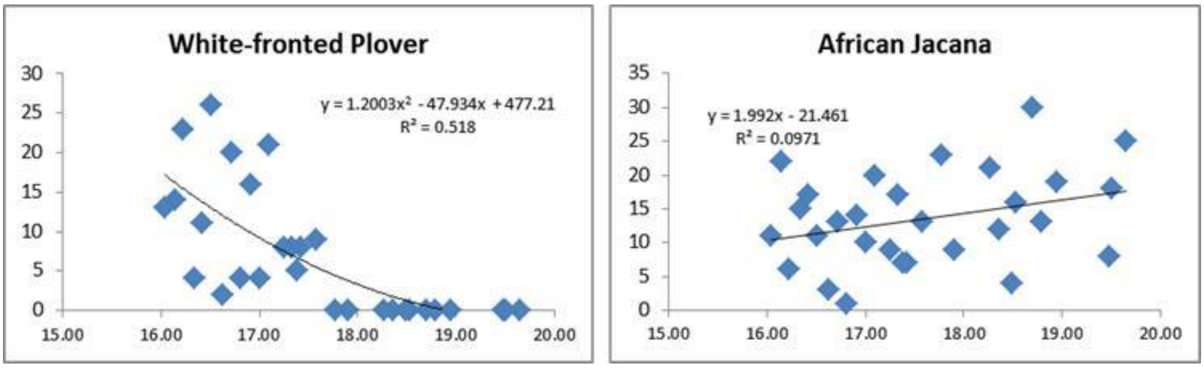

Figure 8.17 Relationships of wader numbers to water level

8.4.3.8 *Gulls and terns*

Grey-headed Gulls and several tern species make use of the lake, with small flocks being recorded on a periodic basis. Grey-headed Gull is a widespread species found along the seashore, at estuaries, coastal lakes, and inland dams and pans. Even at the coast, its breeding colonies are usually associated with freshwater habitats, where it often breeds in reed beds, on islands, shorelines and in old Red-knobbed Coot nests (du Toit *et al*. 2002). While no information was available on breeding activity, it is possible that this species makes use of the lake for breeding while foraging both here and at the coast. Caspian Tern is a widespread species but only breeds at about 14 known localities in the region, with more than half of breeding pairs being recorded at the St Lucia estuary. The birds using Lake Sibaya probably form part of the St Lucia breeding population.

The most numerous terns at Lake Sibaya are the White-winged and Whiskered Terns which prefer freshwater lacustrine environments, as well as Little Tern, a regular summer visitor to the South African coast. Gulls and tern numbers tend to be higher at lower water levels, whereas the lake terns tend to be more common when water levels are 17 – 18 m (Figure 8.18).

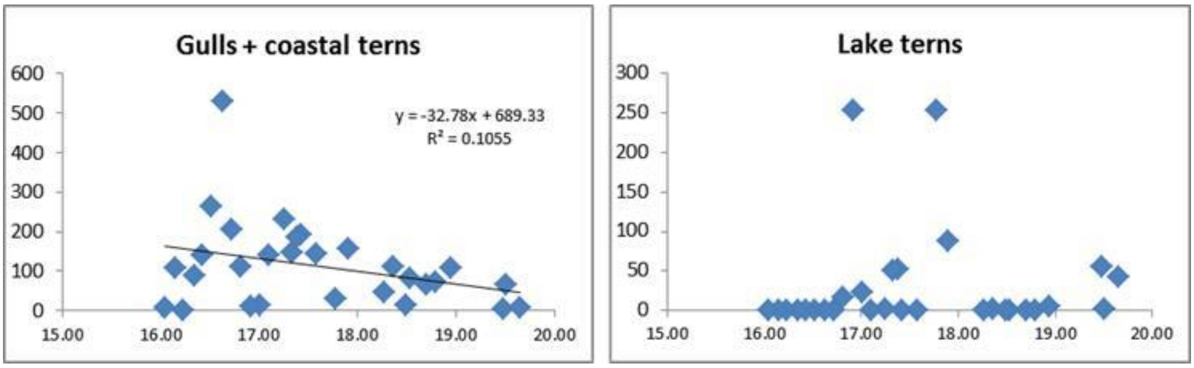

Figure 8.18. Relationships of gull and tern numbers to water level

8.4.3.9 Kingfishers

Pied Kingfisher numbers have remained high across all water levels. Giant and Malachite Kingfishers, on the other hand, are more common at higher water levels (Figure 8.19). During recent counts, numbers of kingfishers have declined as a result of the low water levels.

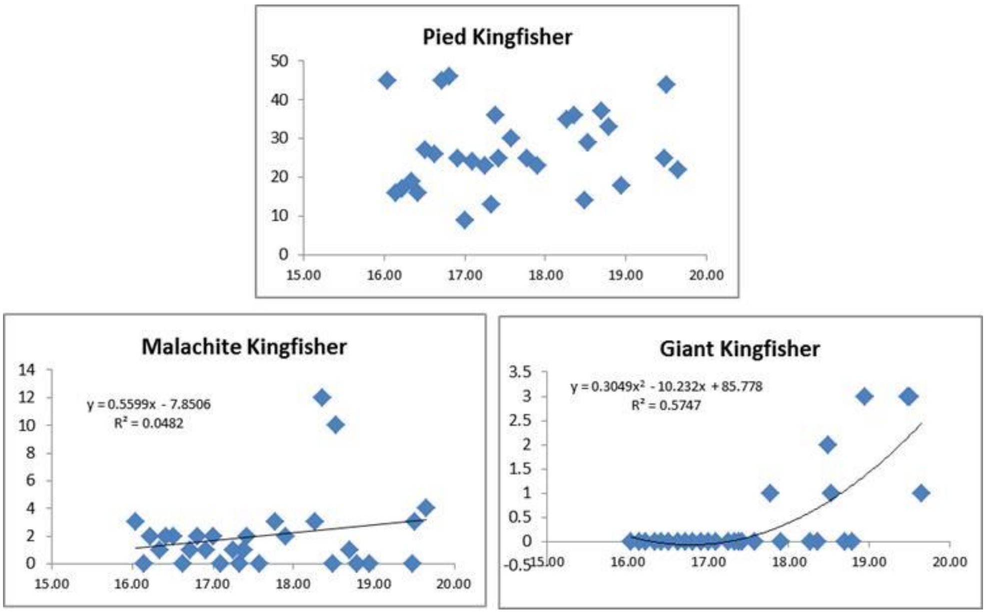

Figure 8.19 Relationships of gull and tern numbers to water level

8.5 Description of indicators used in DRIFT

8.5.1 Indicator list for birds

A list of birds groups used as indicators in the EWR assessments and their expected response to changing water levels is provided in Table 8.2.

The indicators are groups of birds that together make up the avifauna of the lake. The groups are largely divided along taxonomic lines, but are subdivided, not on taxonomic or trophic lines, but in terms of their response to water level. 'Increaser' and 'decreaser' species, with respect to the dropping water level, were identified within each group, and where applicable, larger taxonomic groups were divided on this basis.

Table 8.2 List of bird indicators and their predicted direction of response to water level changes, based on analysis of CWAC data

Indicator	Definition	Predicted change in relation to decreasing water level
Little Grebe	This single species group comprises the only grebe that regularly occurs on the lake. Unlike other waterfowl, it is piscivorous, though also including invertebrates in its diet. It is the dominant species in open water areas.	No change under historical range, but will decrease with further WL decrease.
Cormorants	Overall bird numbers are dominated by two species of cormorant – the White Breasted and Reed Cormorants. These species are piscivorous, breed and roost on marginal trees and feed by diving in deeper parts of the lake.	No change under historical range, but will decrease with further WL decrease.
Darters	This single species group was defined separately from the cormorants as it is responsive to water level. Darters are also piscivorous, breed and roost on marginal trees/reedbeds and feed by diving in deeper parts of the lake, but tend to be found nearer emergent vegetation.	Only occur above threshold water level then responds positively to increased levels.
Wading birds (I)	Wading birds comprise the herons, egrets, ibises, storks and spoonbills. These long-legged species hunt on foot in shallow water, sometimes co-operatively, and feed on small fish, amphibian and invertebrates. Increaser species include Grey Heron and Great Egret.	These species increase as water levels decrease, up to a point, then are expected to decrease.
Wading birds (D)	These are wading bird species that have declined in response to decreasing water level, and include Goliath Heron and Sacred Ibis.	These species decrease as water levels decrease.
Waterfowl (I)	This group comprises the ducks and rallid species. They feed by dabbling or diving or on foot (some rallids), and include a mix of plant matter and invertebrates in their diets, with preferences varying across the group. Increaser species included Spur-winged and Egyptian	These species increase as water levels decrease, up to a point, then are expected to decrease.

Indicator	Definition	Predicted change in relation to decreasing water level
	Goose, Yellow-billed Duck and Red-billed Teal.	
Waterfowl (D)	Decreaser species are the African Pygmy Goose and Black Crake.	These species decrease as water levels decrease.
Waders (I)	Waders are all small species that feed on benthic macroinvertebrates. These include species that are resident as well as summer migrants. The increaser species tend to be the waders that feed on exposed sand/mudflats.	These species increase as water levels decrease, up to a point, then are expected to decrease.
Waders (D)	Decreaser species tend to be the species that feed in backwater areas, marshes and flooded grassland.	These species decrease as water levels decrease.
Gulls & coastal terns (I)	This group comprises Grey-headed Gulls and several species of tern, including Caspian Tern.	These species increase as water levels decrease, up to a point, then are expected to decrease.
Freshwater terns (D)	This group comprises the White-winged and Whiskered Terns that are typically found on large expanses of freshwater (lakes and dams) and feed on small prey at the surface.	These species decrease as water levels decrease.
Kingfishers & birds of prey	This group comprises three species of kingfishers and African Fish Eagle. Other water-associated birds of prey (Osprey, Marsh Harrier) are included in the group, but are only recorded occasionally and in very small numbers.	Numbers are stable under a range of normal water levels but decrease under recent extended decrease in water level.

8.5.2 Linked indicators

The links between the birds and other indicators are summarised below Table 8.3.

Table 8.3 Linked indicators (for motivations, see Section 8.6)

Indicator	Area	Volume	Area of beach	Area 0 – 0.3m deep	Area 1.5 – 2 m deep	Area 0.5 – 1 m deep	Volume up to 2m	Submerged veg	Emergent macroph	Wetlands, pans	Shrimp	Pelagic fish	Tilapia	Other cichlids	Gobies	Catfish
Little Grebe						x			x			x				
Cormorants					x		x						x	x		
Darters					x											
Wading birds (I)		x							x							
Wading birds (D)				x												
Waterfowl (I)									x							
Waterfowl (D)	x									x						
Waders (I)	x		x													
Waders (D)										x						
Gulls & coastal terns (I)			x													
Freshwater terns (D)	x										x	x				
Kingfishers & birds of												x	x	x	x	x

prey	

8.6 Motivations for Response Curves (Tables to be completed by specialist)

8.6.1 *Little Grebe*

<table>
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<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
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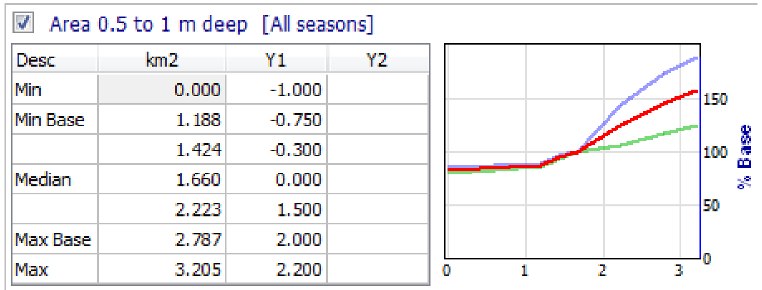
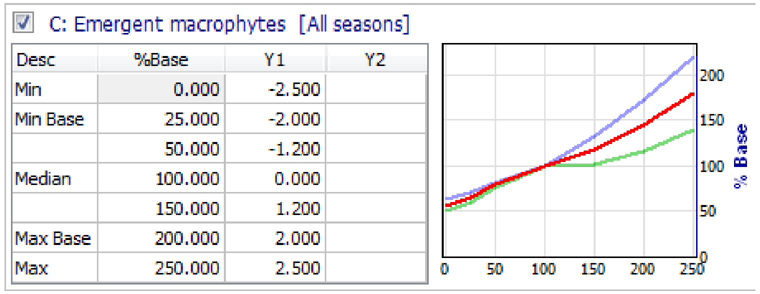
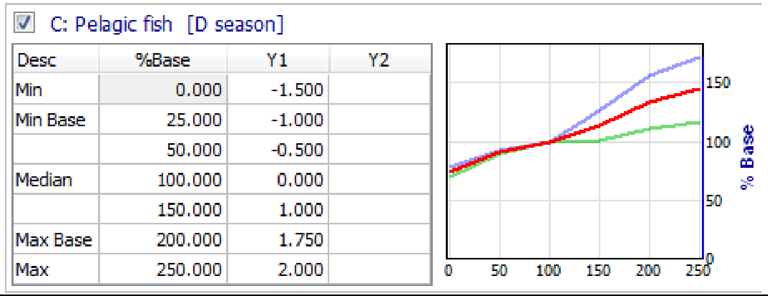

☑ Area 0.5 to 1 m deep [All seasons]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>1.188</td><td>-0.750</td><td></td></tr>
<tr><td></td><td>1.424</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>1.660</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.223</td><td>1.500</td><td></td></tr>
<tr><td>Max Base</td><td>2.787</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>3.205</td><td>2.200</td><td></td></tr>
</table>

</td><td>Little Grebe feed by diving in relatively shallow depths. It has been recorded from a wide range of depths, but usually in wetlands with water deeper than 0.3-0.4 m and with rich vegetation (Fieldsa 2004, Ceccobelli & Battisti 2010, Bilal *et al*. 2013). In shallow wetlands, densities of Little Grebe are positively correlated with maximum water depth in channels, but in wetlands with variable water depths, they avoid diving in areas too deep (>1m) because of the energetic costs (Ceccobelli & Battisti 2010). Thus it is expected that there is a positive relationship between bird numbers and the area of habitat of 0.5-1m deep.</td><td>Medium</td></tr>
<tr><td>

☑ C: Emergent macrophytes [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.500</td><td></td></tr>
</table>

</td><td>Little Grebe are often found areas which are relatively shetered by emergent reed marsh, especially when not feeding. Thus it is expected that there is a positive relationship between bird numbers and abundance of emergent macrophytes.</td><td>Medium</td></tr>
<tr><td>

☑ C: Pelagic fish [D season]
<table>
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<tr><td>Min Base</td><td>25.000</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.750</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.000</td><td></td></tr>
</table>

</td><td>Little Grebe feeds primarily on small pelagic fishes such as *Gilchristella* and *Atherina*. Thus it is expected that there is a positive relationship between bird numbers and abundance of small pelagic fish.</td><td>Medium</td></tr>
</table>

8.6.2 *Cormorants*

<table>
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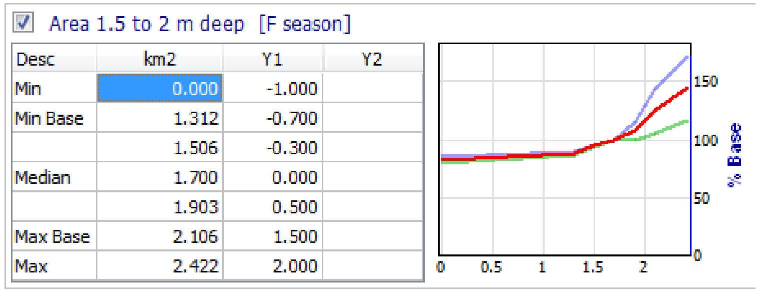
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area 1.5 to 2 m deep [F season]
<table>
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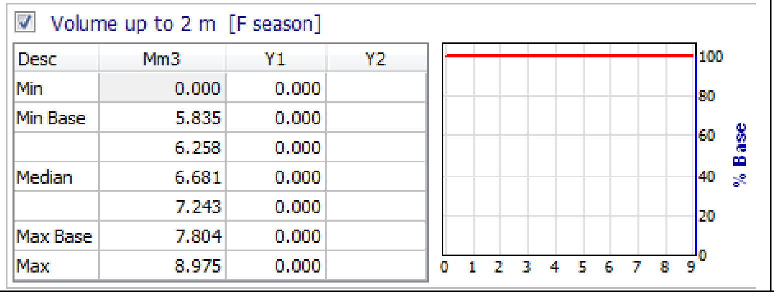
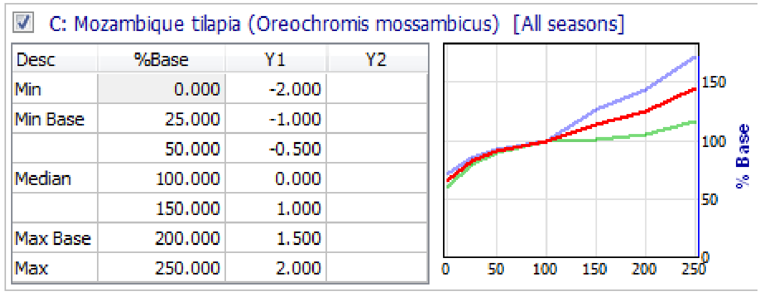
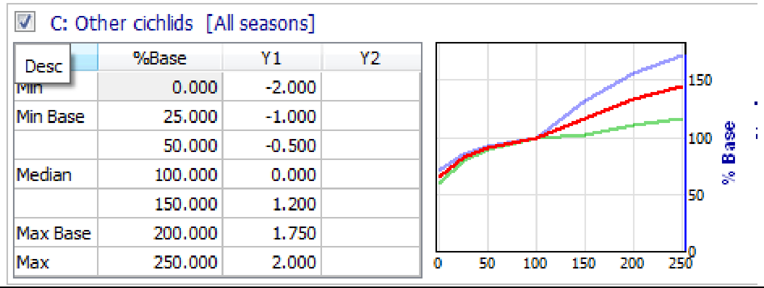
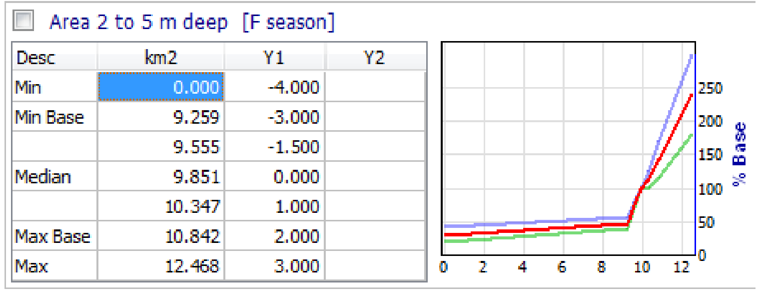
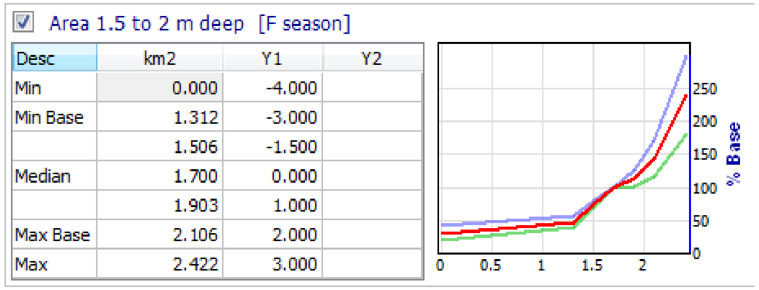
<tr><td>Min Base</td><td>1.312</td><td>-0.700</td><td></td></tr>
<tr><td></td><td>1.506</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>1.700</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.903</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>2.106</td><td>1.500</td><td></td></tr>
<tr><td>Max</td><td>2.422</td><td>2.000</td><td></td></tr>
</table>
</td><td>White-breasted and Reed Cormorants breed and roost on marginal trees and feed by swimming in fast pursuit of small to medium-sized fish which they catch with a hooked bill. Studies of Reed Cormorants in Lake Kariba suggest that they dive to an average depth of about 2 m (Birkhead 1978). At Lake St Lucia, Reed Cormorants foraged in shallow water of 30 cm to 2 m depth within 100 m of the shore (Whitfield & Blaber 1979). Whitebreasted Cormorant fished in deeper water, usually between 10 m and 200 m from the shore, but up to 1 km (Whitfield & Blaber 1979). At Lake Sibaya, numbers of cormorants were not correlated with water level. Numbers increased dramatically from the 1990s to the mid-2000s, then started to decrease again as lake levels declined. One possible reason for this pattern is an influx of birds from surrounding areas as a result of drought. Lake St Lucia, for example, experienced extremely low water levels during the early to mid-2000s. It was not possible to model these external influences. Nevertheless it was assumed that the population would be negatively affected by a decrease in water level.</td><td>Medium</td></tr>
<tr><td>
☑ Volume up to 2 m [F season]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>5.835</td><td>0.000</td><td></td></tr>
<tr><td></td><td>6.258</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>6.681</td><td>0.000</td><td></td></tr>
<tr><td></td><td>7.243</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>7.804</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>8.975</td><td>0.000</td><td></td></tr>
</table>
</td><td></td><td>Medium</td></tr>
</table>

<table>
<tr><th colspan="2">Name: Cormorants</th><th></th></tr>
<tr><th>Linked indicator response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>
☑ C: Mozambique tilapia (Oreochromis mossambicus) [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.000</td><td></td></tr>
</table>
</td>
<td>Cormorant diets at Lake Sibaya are dominated by gobies and cichlids (Bruton 1979). Thus it is expected that there is a positive relationship between bird numbers and abundance of these species. In Lake Kariba, Reed Cormorant numbers have been shown to be related to fish abundance (Junor <i>et al</i>. 1987).</td>
<td>Medium</td></tr>
<tr><td>
☑ C: Other cichlids [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.750</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.000</td><td></td></tr>
</table>
</td>
<td>Cormorant diets at Lake Sibaya are dominated by gobies and cichlids (Bruton 1979). Thus it is expected that there is a positive relationship between bird numbers and abundance of these species. In Lake Kariba, Reed Cormorant numbers have been shown to be related to fish abundance (Junor <i>et al.</i> 1987).</td>
<td>Medium</td></tr>
</table>

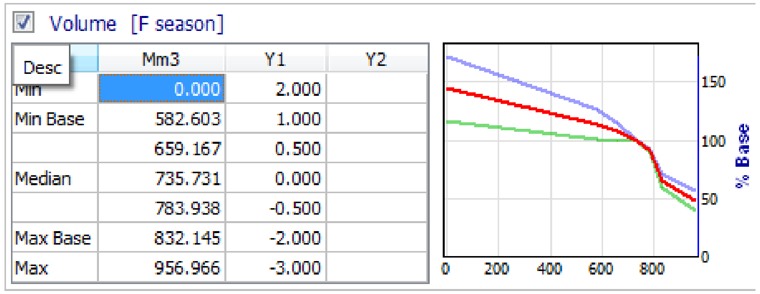
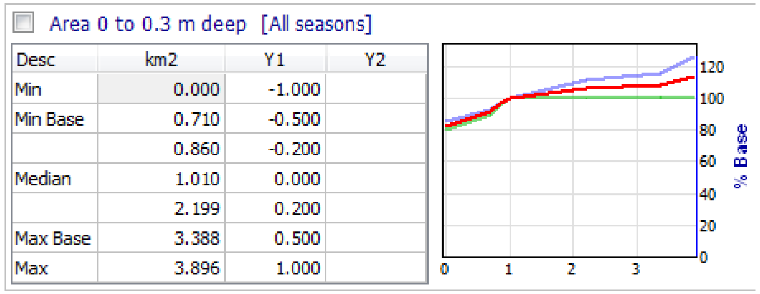
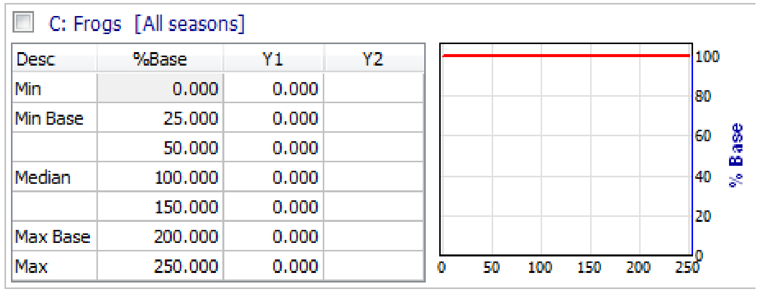
8.6.3 *Darters*

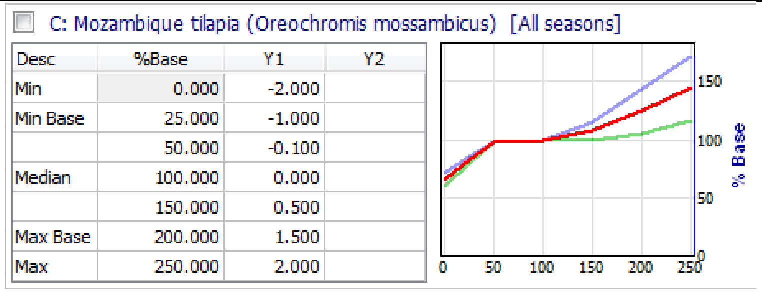
<table>
<tr><td colspan="2">Name: Darters</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☐ Area 2 to 5 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-4.000</td><td></td></tr>
<tr><td>Min Base</td><td>9.259</td><td>-3.000</td><td></td></tr>
<tr><td></td><td>9.555</td><td>-1.500</td><td></td></tr>
<tr><td>Median</td><td>9.851</td><td>0.000</td><td></td></tr>
<tr><td></td><td>10.347</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>10.842</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>12.468</td><td>3.000</td><td></td></tr>
</table></td><td></td><td>Medium</td></tr>
<tr><td>

☑ Area 1.5 to 2 m deep [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-4.000</td><td></td></tr>
<tr><td>Min Base</td><td>1.312</td><td>-3.000</td><td></td></tr>
<tr><td></td><td>1.506</td><td>-1.500</td><td></td></tr>
<tr><td>Median</td><td>1.700</td><td>0.000</td><td></td></tr>
<tr><td></td><td>1.903</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>2.106</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>2.422</td><td>3.000</td><td></td></tr>
</table></td><td>Darters feed by swimming under water in pursuit of small to medium sized pelagic fish at an average of 2 m depth. Given the disappearance of this species below water levels of 17 m, this suggests that the area of water of 1.5 – 2 m depth is an important driver.</td><td>Medium</td></tr>
</table>

8.6.4 *Wading birds (I)*

<table>
<tr><td colspan="2">Name: Wading birds (I)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Volume [F season]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>2.000</td><td></td></tr>
<tr><td>Min Base</td><td>582.603</td><td>1.000</td><td></td></tr>
<tr><td></td><td>659.167</td><td>0.500</td><td></td></tr>
<tr><td>Median</td><td>735.731</td><td>0.000</td><td></td></tr>
<tr><td></td><td>783.938</td><td>-0.500</td><td></td></tr>
<tr><td>Max Base</td><td>832.145</td><td>-2.000</td><td></td></tr>
<tr><td>Max</td><td>956.966</td><td>-3.000</td><td></td></tr>
</table>
</td><td>Wading birds are the relatively long-legged species of herons, egrets that feed by wading in water depths up to about 20-30 cm in search of fish and amphibians which they catch by rapidly darting at them, ibises which feed by probing in the mud for invertebrates, and spoonbill which feed on fish and invertebrates by dabbling. Increaser species include Little Egret, Grey Heron, Purple Heron, Goliath Heron and Great Egret, and Saddle billed Stork. These species are most abundant at intermediate water levels, probably because of the interaction between prey accessibility (which increases as WL recedes) and reedmarsh availability (which increases with WL). Inverse of volume was used as a proxy for the former.</td><td>Medium</td></tr>
<tr><td>
☐ Area 0 to 0.3 m deep [All seasons]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.710</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>0.860</td><td>-0.200</td><td></td></tr>
<tr><td>Median</td><td>1.010</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.199</td><td>0.200</td><td></td></tr>
<tr><td>Max Base</td><td>3.388</td><td>0.500</td><td></td></tr>
<tr><td>Max</td><td>3.896</td><td>1.000</td><td></td></tr>
</table>
</td><td></td><td>Medium</td></tr>
<tr><td>
☐ C: Frogs [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>
</td><td></td><td>Medium</td></tr>
</table>

<table>
<tr><th colspan="2">Name: Wading birds (I)</th><th></th></tr>
<tr><th>Linked indicator response curve</th><th>Explanation</th><th>Confidence</th></tr>
<tr><td>


☐ C: Mozambique tilapia (Oreochromis mossambicus) [All seasons]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.100</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.000</td><td></td></tr>
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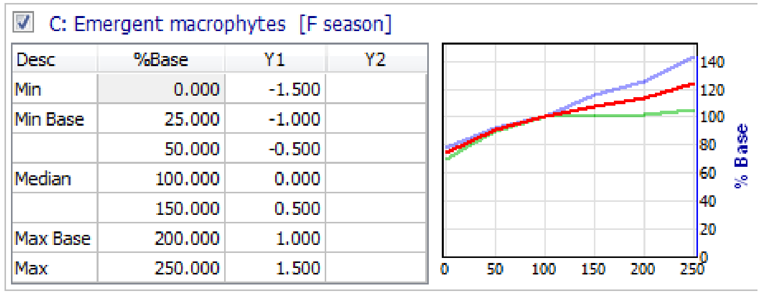
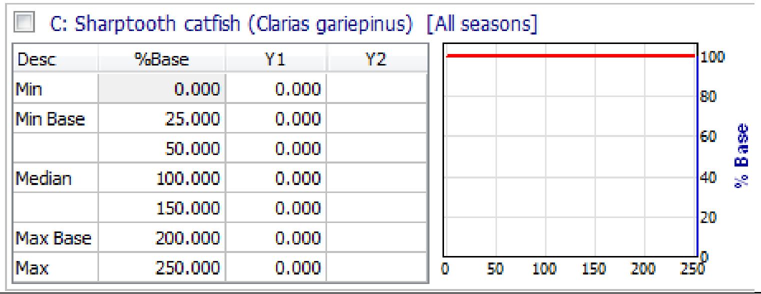
</td><td></td><td>Medium</td></tr>
<tr><td>


☑ C: Emergent macrophytes [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.500</td><td></td></tr>
</table>

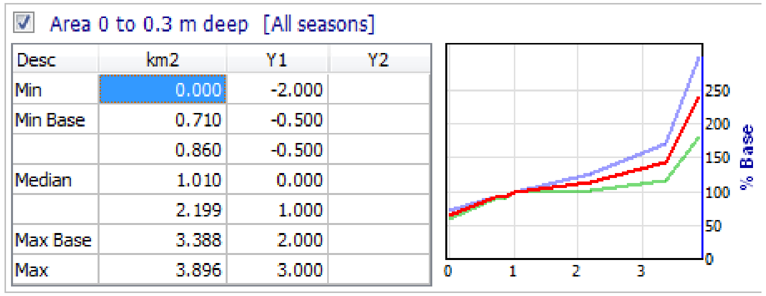
</td><td></td><td>Medium</td></tr>
<tr><td>


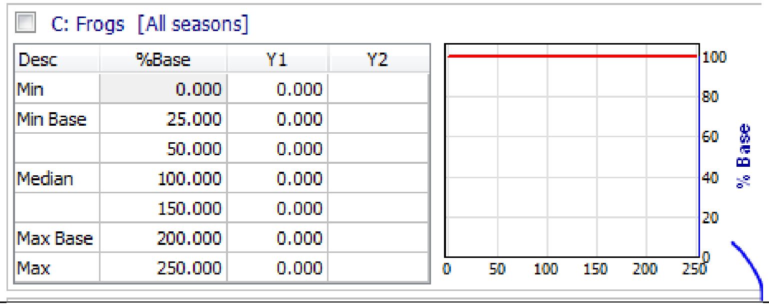
☐ C: Sharptooth catfish (Clarias gariepinus) [All seasons]

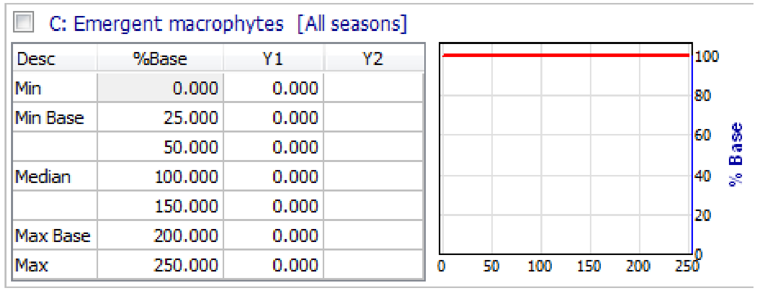
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>

</td><td></td><td>Medium</td></tr>
</table>

8.6.5 *Wading birds (D)*

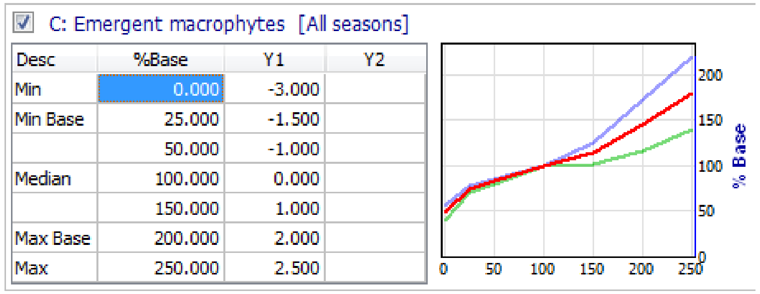
<table>
<tr><td colspan="2">Name: Wading birds (D)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>


<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.710</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>0.860</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>1.010</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.199</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>3.388</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>3.896</td><td>3.000</td><td></td></tr>
</table>
</td><td>These are wading bird species that have declined in response to decreasing water level, and include Squacco Heron and Sacred Ibis. Both only common at high water levels.</td><td>Medium</td></tr>
<tr><td>


<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>
</td><td></td><td>Medium</td></tr>
<tr><td>


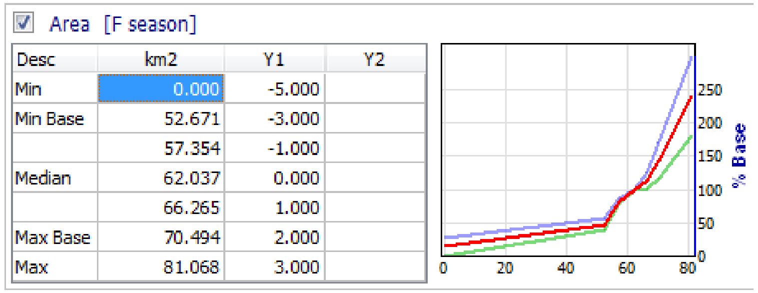
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>
</td><td></td><td>Medium</td></tr>
</table>

8.6.6 *Waterfowl (I)*

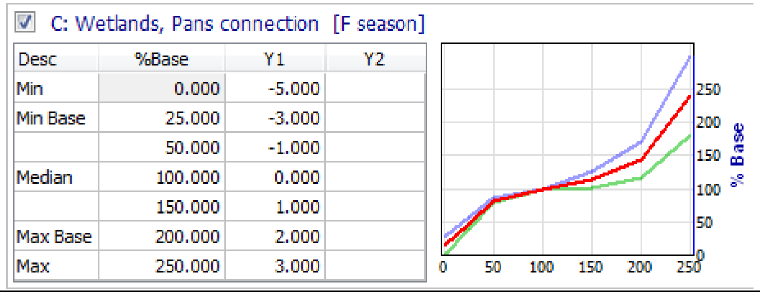
<table>
<tr><td colspan="2">Name Water fowl (I)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ C: Emergent macrophytes [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.500</td><td></td></tr>
</table>

</td><td>Increaser species included Spur-winged and Egyptian Goose, Yellow-billed Duck and Red-billed Teal. These species increase as water levels decrease, up to a point, then are expected to decrease. Increases in Geese possibly exogenous. YB Duck and RB Teal favour wetlands rich in emergent reed marsh.
OR This group comprises the ducks and rallid species. They feed by dabbling or diving or on foot (some rallids), and include a mix of plant matter and invertebrates in their diets, with preferences varying across the group. Increaser species included Spur-winged and Egyptian Goose, Yellow-billed Duck and Red-billed Teal. The waterfowl species that increase with decreasing water level are probably doing so largely in relation to decreasing availability of suitable habitat elsewhere.</td><td>Medium</td></tr>
</table>

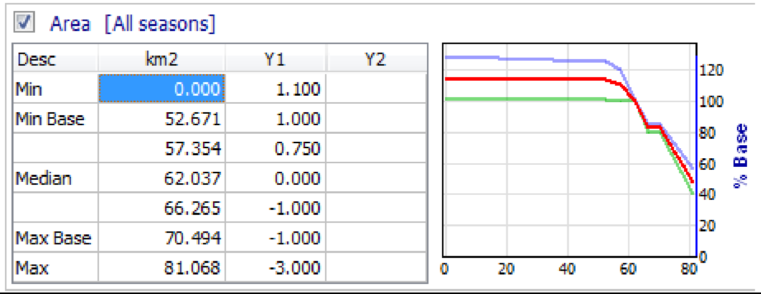
8.6.7 *Water fowl (D)*

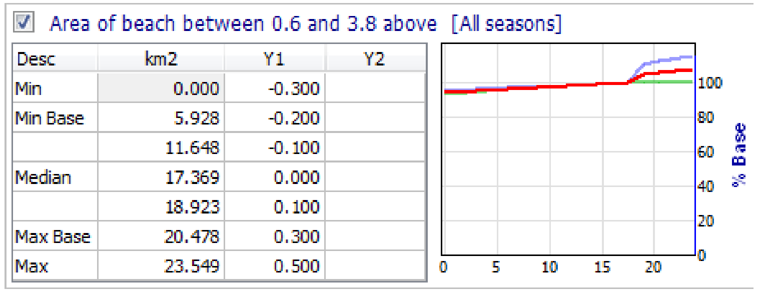
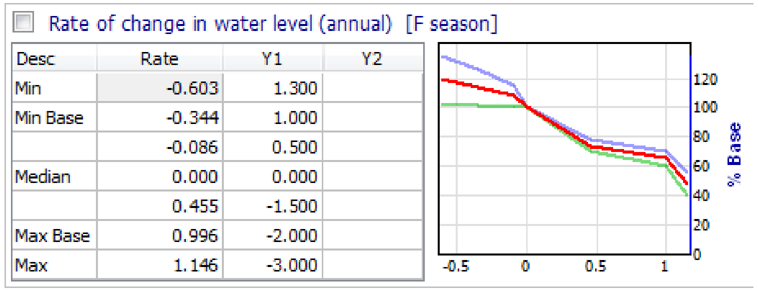
<table>
<tr><td colspan="2">Name: Water fowl (D)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Area [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>52.671</td><td>-3.000</td><td></td></tr>
<tr><td></td><td>57.354</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>62.037</td><td>0.000</td><td></td></tr>
<tr><td></td><td>66.265</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>70.494</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>81.068</td><td>3.000</td><td></td></tr>
</table>

</td><td>Numbers of African Pygmy Goose and Black Crake are positively correlated with water level. At very high water levels, the area of flooded vegetated habitat increases. Thus area was used as a proxy for this.</td><td>Medium</td></tr>
</table>

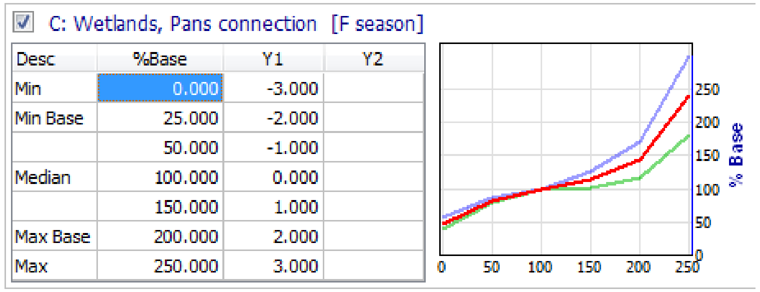
<table>
<tr><td colspan="2">Name: Water fowl (D)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ C: Wetlands, Pans connection [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-3.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.000</td><td></td></tr>
</table>
</td><td>Numbers of African Pygmy Goose and Black Crake are positively correlated with water level. At very high water levels, the area of flooded vegetated habitat increases. Thus area was used as a proxy for this.</td><td></td></tr>
</table>

8.6.8 *Waders (I)*

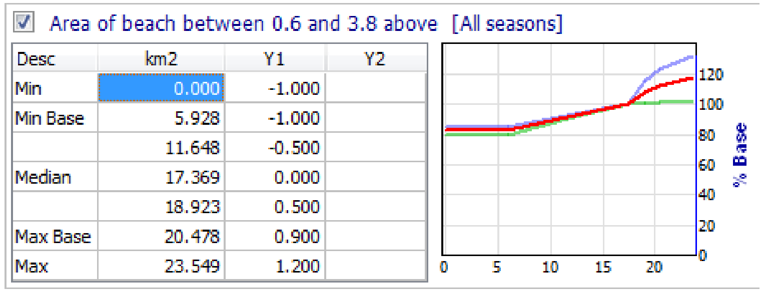
<table>
<tr><td colspan="2">Name: Waders (I)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area [All seasons]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.100</td><td></td></tr>
<tr><td>Min Base</td><td>52.671</td><td>1.000</td><td></td></tr>
<tr><td></td><td>57.354</td><td>0.750</td><td></td></tr>
<tr><td>Median</td><td>62.037</td><td>0.000</td><td></td></tr>
<tr><td></td><td>66.265</td><td>-1.000</td><td></td></tr>
<tr><td>Max Base</td><td>70.494</td><td>-1.000</td><td></td></tr>
<tr><td>Max</td><td>81.068</td><td>-3.000</td><td></td></tr>
</table>
</td><td></td><td></td></tr>
</table>

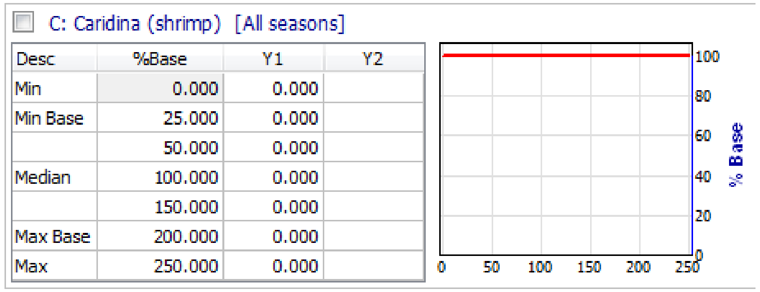
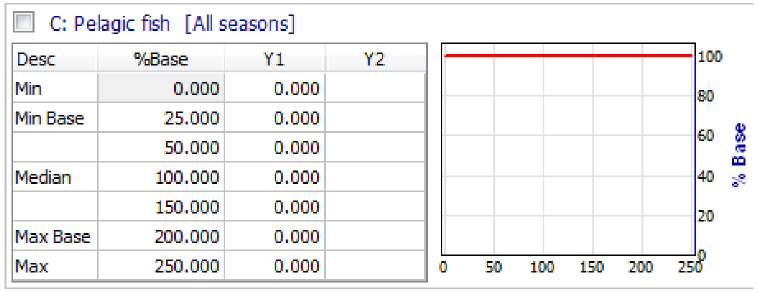
<table>
<tr><td colspan="2">Name: Waders (I)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area of beach between 0.6 and 3.8 above [All seasons]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.300</td><td></td></tr>
<tr><td>Min Base</td><td>5.928</td><td>-0.200</td><td></td></tr>
<tr><td></td><td>11.648</td><td>-0.100</td><td></td></tr>
<tr><td>Median</td><td>17.369</td><td>0.000</td><td></td></tr>
<tr><td></td><td>18.923</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>20.478</td><td>0.300</td><td></td></tr>
<tr><td>Max</td><td>23.549</td><td>0.500</td><td></td></tr>
</table>
</td><td>There is a strongly negative relationship between White-fronted Plover numbers and water level, because the amount of beach available to birds increases as the lake levels drop. There is clearly very little beach habitat above 17.5 m.</td><td>Medium</td></tr>
<tr><td>
☐ Rate of change in water level (annual) [F season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>1.300</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>1.000</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.500</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>-1.500</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>-2.000</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>-3.000</td><td></td></tr>
</table>
</td><td></td><td>Medium</td></tr>
</table>

8.6.9 *Waders (D)*

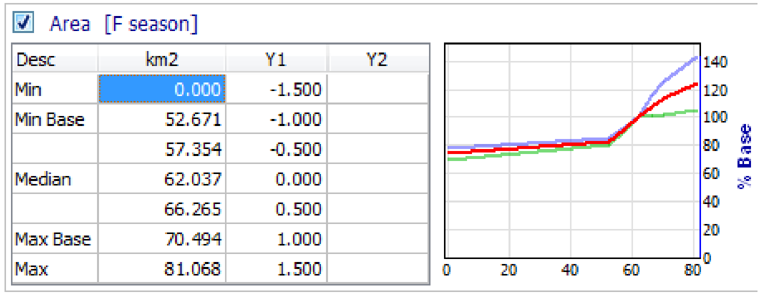
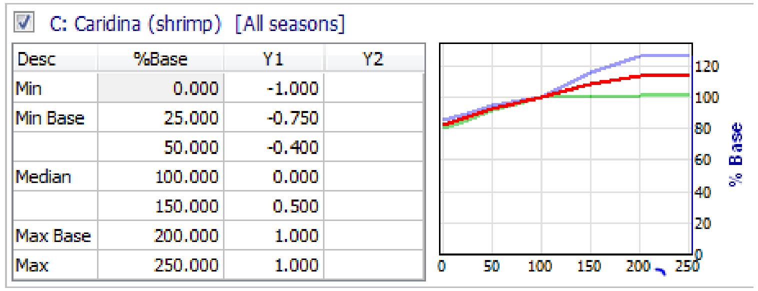
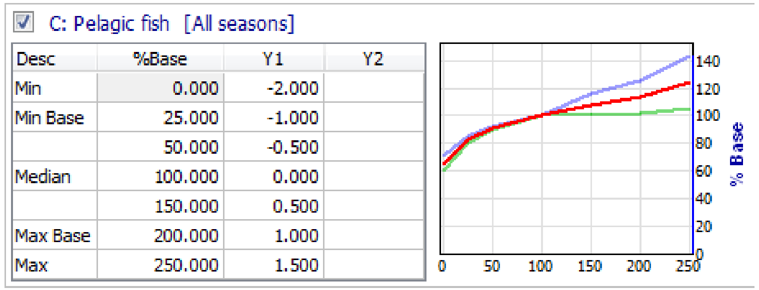
<table>
<tr><td colspan="2">Name: Waders (D)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
<p>☑ C: Wetlands, Pans connection [F season]</p>
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.000</td><td></td></tr>
</table>
</td><td>African Jacana numbers (variable because they are a relatively shy species) increase slightly at higher water levels.</td><td>Medium</td></tr>
</table>

8.6.10 *Gulls and coastal terns (I)*

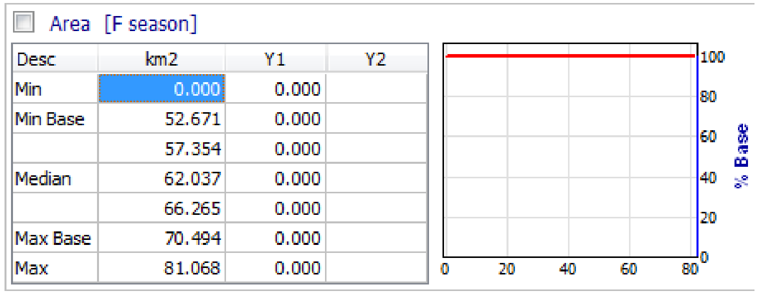
<table>
<tr><td colspan="2">Name: Gulls and coastal terns (I)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
<p>☑ Area of beach between 0.6 and 3.8 above [All seasons]</p>
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>5.928</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>11.648</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>17.369</td><td>0.000</td><td></td></tr>
<tr><td></td><td>18.923</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>20.478</td><td>0.900</td><td></td></tr>
<tr><td>Max</td><td>23.549</td><td>1.200</td><td></td></tr>
</table>
</td><td>Grey-headed Gulls and several tern species make use of the lake, with small flocks being recorded on a periodic basis. Caspian Tern is an important species that breeds in the area. Gull and tern numbers tend to be higher at lower water levels. This is influenced by availability of beach areas suitable for roosting.</td><td>Medium</td></tr>
</table>

<table>
<tr><td colspan="2">Name: Gulls and coastal terns (I)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☐ C: Caridina (shrimp) [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>
</td><td></td><td>Medium</td></tr>
<tr><td>
☐ C: Pelagic fish [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>
</td><td></td><td>Medium</td></tr>
</table>

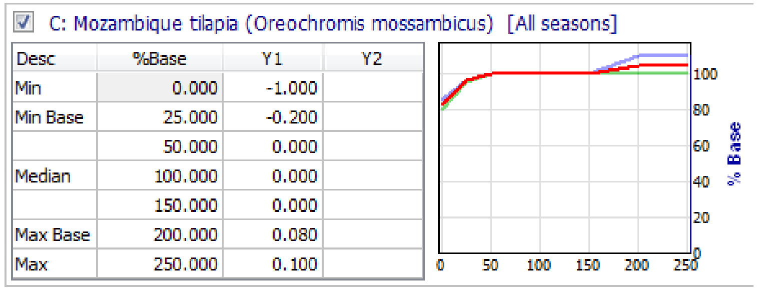
8.6.11 *Freshwater terns (D)*

<table>
<tr><td colspan="2">Name: Freshwater terns (D)</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Area [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.500</td><td></td></tr>
<tr><td>Min Base</td><td>52.671</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>57.354</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>62.037</td><td>0.000</td><td></td></tr>
<tr><td></td><td>66.265</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>70.494</td><td>1.000</td><td></td></tr>
<tr><td>Max</td><td>81.068</td><td>1.500</td><td></td></tr>
</table>
</td><td>The most numerous terns at Lake Sibaya are the White-winged and Whiskered Terns which prefer freshwater lacustrine environments. Numbers are highly variable. They tend to be more common when water levels are 17 – 18 m. Numbers are expected to decline with decreasing lake levels.</td><td>Medium</td></tr>
<tr><td>
☑ C: Caridina (shrimp) [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.750</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.400</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.000</td><td></td></tr>
</table>
</td><td></td><td>Medium</td></tr>
<tr><td>
☑ C: Pelagic fish [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.500</td><td></td></tr>
</table>
</td><td></td><td>Medium</td></tr>
<tr><td colspan="3"></td></tr>
</table>

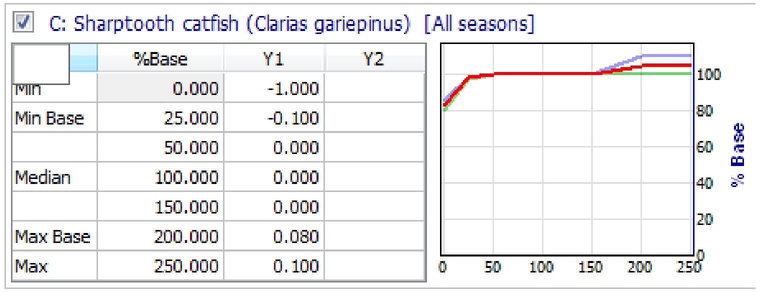
8.6.12 *Kingfishers and birds of prey*

<table>
<tr><td colspan="2">Name King fishers and birds of prey</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☐ Area [F season]

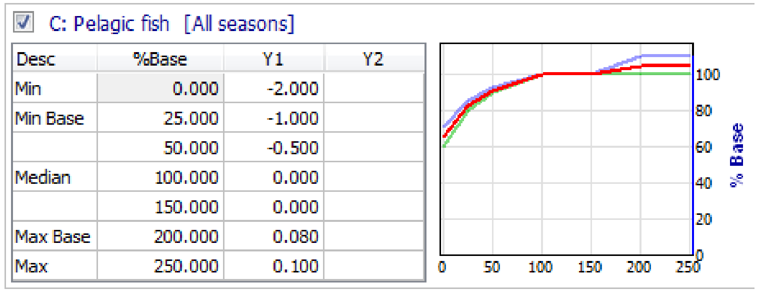
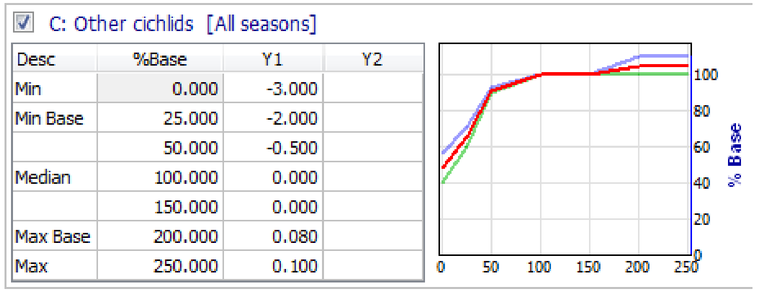
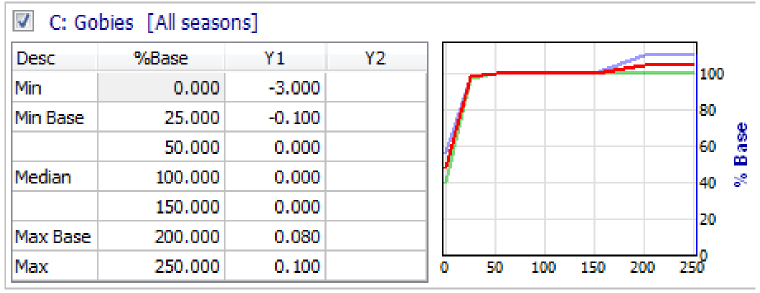
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>52.671</td><td>0.000</td><td></td></tr>
<tr><td></td><td>57.354</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>62.037</td><td>0.000</td><td></td></tr>
<tr><td></td><td>66.265</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>70.494</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>81.068</td><td>0.000</td><td></td></tr>
</table></td><td></td><td></td></tr>
<tr><td>

☑ C: Mozambique tilapia (Oreochromis mossambicus) [All seasons]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.200</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.080</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.100</td><td></td></tr>
</table></td><td>Both African Fish Eagle and Pied Kingfisher numbers have remained high across all water levels. During recent counts, numbers of kingfishers have declined as a result of the low water levels. Giant and Malachite Kingfishers, on the other hand, are more common at higher water levels, as are sightings of other water associated birds of prey. All of these are piscivorous species, preying on a variety of small fishes (in the case of kingfishers) and larger species (in the case of fish eagles). Numbers of these birds have been related to abundance of fish, all of which decline with decreasing water levels.</td><td>Medium</td></tr>
<tr><td>

☑ C: Sharptooth catfish (Clarias gariepinus) [All seasons]

<table>
<tr><th></th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.100</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.080</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.100</td><td></td></tr>
</table></td><td></td><td></td></tr>
</table>

Name King fishers and birds of prey		
Linked indicator response curve	Explanation	Confidence
		
		
		

☑ C: Pelagic fish [All seasons]

Desc	%Base	Y1	Y2
Min	0.000	-2.000	
Min Base	25.000	-1.000	
	50.000	-0.500	
Median	100.000	0.000	
	150.000	0.000	
Max Base	200.000	0.080	
Max	250.000	0.100	

☑ C: Other cichlids [All seasons]

Desc	%Base	Y1	Y2
Min	0.000	-3.000	
Min Base	25.000	-2.000	
	50.000	-0.500	
Median	100.000	0.000	
	150.000	0.000	
Max Base	200.000	0.080	
Max	250.000	0.100	

☑ C: Gobies [All seasons]

Desc	%Base	Y1	Y2
Min	0.000	-3.000	
Min Base	25.000	-0.100	
	50.000	0.000	
Median	100.000	0.000	
	150.000	0.000	
Max Base	200.000	0.080	
Max	250.000	0.100	

8.7 EcoClassification of the lake for birds

Lake Sibaya is a large lake that forms part of a very rich complex of wetlands on the Maputaland coastal plain. As such it is of high conservation importance, especially during the dry season when it is thought to act as a refuge when other more seasonal wetlands have dried out. Seven regional Red Data species have been recorded at the site:

- White-backed Night-Heron
- Saddle-billed Stork
- Greater Flamingo
- African Pygmy-Goose
- African Marsh-Harrier
- Lesser Jacana
- Caspian Tern

Of these the site is important for African Pygmy Goose and Caspian Tern.

This assessment rated the whole of Lake Sibaya as a Category B for birds, and this was extrapolated to all the five EWR zones.

8.8 Raw CWAC bird count data

Table 8.4 CWAC bird count data

Species	Mar-70	May-76	Dec-81	Jul-92	Jan-93	Jul-93	Aug-94	Jul-95	Jan-96	Aug-96	Feb-97	Jul-97	Jul-99	Feb-05	Jul-05	Jan-06	Jul-06	Feb-07	Jul-07	Feb-08	Jul-08	Jan-09	Jul-09	Jan-10	Jul-10	Jan-11	Aug-11	Feb-12	Jul-12	Feb-13
WATER LEVEL MASL	17.504	20.134	18.926	19.655	19.485	19.509	18.941	18.699	18.789	18.534	18.355	18.264	18.493	17.899	17.777	17.582	17.424	17.379	17.33	17.252	17.1	17.004	16.91	16.814	16.72	16.625	16.514	16.419	16.34	16.229
Little Grebe	100	26	0	117	0	57	57	97	2	139	5	87	108	78	124	5	82	57	78	8	184	5	120	9	88	0	114	26	79	5
White-breasted Cormorant	93	241	111	201	256	111	98	87	466	23	378	34	19	336	337	597	261	349	294	404	289	472	289	385	231	175	223	251	249	147
Reed Cormorant	289	51	438	324	283	208	382	340	6	25	43	145	125	605	604	385	209	283	333	33	419	119	493	192	356	27	364	372	308	24
African Darter	0	14	15	31	13	19	12	8	1	0	2	19	2	0	2	0	0	0	0	1	0	0	0	1	2	0	0	0	4	0
Grey Heron			2	1	4	2	1	3	2	0	5	2	4	16	27	9	7	3	6	0	4	11	5	8	9	14	7	9	10	4
Goliath Heron			1	4	3	4	3	3	6	1	4	5	2	10	9	8	4	0	3	1	6	1	1	2	5	1	3	6	1	0
Purple Heron	34	9	1	4	5	1	0	3	4	2	21	3	3	23	2	28	2	12	1	10	5	24	2	17	2	9	1	36	4	11
Great Egret			17	3	1	5	5	2	0	4	0	2	0	4	3	1	2	1	3	1	3	10	6	2	4	6	4	0	1	0
Little Egret			27	14	0	22	21	34	4	12	17	15	18	17	60	27	42	3	12	0	36	18	30	9	9	3	20	1	5	2
Yellow-billed Egret				0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	6	0	0	0	0	1
Squacco Heron				6	0	4	7	1	0	7	3	3	6	1	3	1	0	1	3	0	1	1	1	0	1	0	3	0	0	1
Green-backed Heron				1	2	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Black Heron				0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Dwarf Bittern				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Little Bittern				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Black-crowned Night-Heron				0	0	0	1	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Species	Mar-70	May-76	Dec-81	Jul-92	Jan-93	Jul-93	Aug-94	Jul-95	Jan-96	Aug-96	Feb-97	Jul-97	Jul-99	Feb-05	Jul-05	Jan-06	Jul-06	Feb-07	Jul-07	Feb-08	Jul-08	Jan-09	Jul-09	Jan-10	Jul-10	Jan-11	Aug-11	Feb-12	Jul-12	Feb-13
WATER LEVEL MASL	17.504	20.134	18.926	19.655	19.485	19.509	18.941	18.699	18.789	18.534	18.355	18.264	18.493	17.899	17.777	17.582	17.424	17.379	17.33	17.252	17.1	17.004	16.91	16.814	16.72	16.625	16.514	16.419	16.34	16.229
White-backed Night-Heron				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hamerkop				0	5	0	2	0	7	2	3	0	1	5	1	6	3	0	2	4	4	1	0	0	0	0	1	4	2	7
Saddle-billed Stork				0	0	0	0	0	0	0	0	0	0	2	2	0	1	2	0	2	2	2	2	3	1	1	2	0	0	2
Woolly-necked Stork				0	0	0	0	0	4	0	2	0	0	1	0	0	0	2	0	1	0	2	3	3	1	0	1	1	0	0
African Sacred Ibis				14	1	19	15	6	0	5	0	10	11	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Glossy Ibis				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Hadeda Ibis	3	29		1	0	2	25	1	2	9	6	4	6	4	7	13	4	13	4	2	9	2	1	2	6	0	3	25	3	1
African Spoonbill				0	0	0	0	9	0	0	0	3	0	1	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Greater Flamingo				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spur-winged Goose			8	0	5	0	21	8	9	9	12	5	6	21	20	25	3	12	9	11	11	29	5	8	5	6	22	17	2	23
Egyptian Goose				2	0	2	3	3	5	2	1	3	2	25	29	14	15	24	34	53	51	70	82	12	84	70	100	171	65	43
Comb Duck				0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
African Pygmy-Goose	8	7		74	4	2	7	49	0	4	0	12	2	0	6	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0
Yellow-billed Duck			2	0	0	0	3	11	6	6	10	3	7	45	109	30	15	44	31	97	23	60	21	0	15	10	14	0	31	17
Red-billed Teal				0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0	15	6	6	3	0	0	26	9	21	0
White-faced Duck				1	4	5	133	28	16	24	7	56	9	16	21	37	0	29	0	8	12	2	0	16	0	2	0	0	30	0
Fulvous Duck				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
White-backed Duck				0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
African Fish-Eagle	8	13	5	13	16	12	12	13	10	7	8	9	8	14	19	9	9	10	9	9	15	17	8	7	17	8	7	7	4	5
African Marsh-Harrier				1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Osprey				0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0

Species	Mar-70	May-76	Dec-81	Jul-92	Jan-93	Jul-93	Aug-94	Jul-95	Jan-96	Aug-96	Feb-97	Jul-97	Jul-99	Feb-05	Jul-05	Jan-06	Jul-06	Feb-07	Jul-07	Feb-08	Jul-08	Jan-09	Jul-09	Jan-10	Jul-10	Jan-11	Aug-11	Feb-12	Jul-12	Feb-13
WATER LEVEL MASL	17.504	20.134	18.926	19.655	19.485	19.509	18.941	18.699	18.789	18.534	18.355	18.264	18.493	17.899	17.777	17.582	17.424	17.379	17.33	17.252	17.1	17.004	16.91	16.814	16.72	16.625	16.514	16.419	16.34	16.229
Black Crake	4	17		16	5	6	1	4	1	1	2	2	1	0	4	4	1	0	1	1	1	0	2	0	6	0	5	3	0	1
African Purple Swamphen				7	0	1	0	10	1	3	4	2	1	4	0	0	3	1	2	0	9	12	7	1	3	0	4	5	1	1
Allen's Gallinule				2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common Moorhen				1	0	1	1	7	21	13	5	3	3	6	16	10	2	2	4	4	5	2	14	7	14	3	11	5	16	1
Red-knobbed Coot				0	0	0	0	14	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Common Ringed Plover				0	0	0	0	0	4	3	1	0	0	1	0	0	0	1	0	1	0	5	0	0	0	0	0	0	0	0
Greater Sand Plover				0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curlew Sandpiper				0	0	0	0	0	0	0	0	0	0	0	0	39	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Little Stint				0	0	0	0	0	1	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common Sandpiper			1	0	0	0	0	0	0	3	6	0	0	17	0	13	0	2	0	4	0	0	0	0	0	0	0	8	0	0
Common Greenshank			8	0	0	0	1	3	21	11	19	0	1	26	4	48	121	10	4	12	6	9	1	5	0	8	4	24	0	11
White-fronted Plover				0	0	0	0	0	0	0	0	0	0	0	0	9	8	5	8	8	21	4	16	4	20	2	26	11	4	23
Collared Pratincole				0	0	0	0	0	2	0	0	0	0	1	0	0	4	6	0	17	0	1	0	0	0	0	0	2	0	0
Ruff			4	0	0	0	0	0	0	0	0	0	0	6	0	3	0	0	0	6	0	3	0	1	0	0	0	3	0	0
African Jacana	9	46		25	8	18	19	30	13	16	12	21	4	9	23	13	7	7	17	9	20	10	14	1	13	3	11	17	15	6
Lesser Jacana				2	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blacksmith Lapwing				0	0	0	1	1	6	2	7	5	2	3	7	4	1	3	0	3	3	6	5	5	14	15	9	26	10	9
African Wattled Lapwing				2	0	2	1	0	6	7	8	0	0	17	3	7	0	0	0	0	0	0	0	7	7	5	2	3	0	9
Pied Avocet				0	0	0	0	0	0	3	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0
Black-winged Stilt	25	0	2	11	0	10	17	40	18	2	8	15	4	58	43	33	16	2	4	7	16	15	23	13	15	1	43	67	58	7
Water Thick-knee				0	3	0	0	0	7	0	0	0	0	8	0	4	1	4	2	3	3	6	2	3	0	0	2	8	0	22

Species	Mar-70	May-76	Dec-81	Jul-92	Jan-93	Jul-93	Aug-94	Jul-95	Jan-96	Aug-96	Feb-97	Jul-97	Jul-99	Feb-05	Jul-05	Jan-06	Jul-06	Feb-07	Jul-07	Feb-08	Jul-08	Jan-09	Jul-09	Jan-10	Jul-10	Jan-11	Aug-11	Feb-12	Jul-12	Feb-13
WATER LEVEL MASL	17.504	20.134	18.926	19.655	19.485	19.509	18.941	18.699	18.789	18.534	18.355	18.264	18.493	17.899	17.777	17.582	17.424	17.379	17.33	17.252	17.1	17.004	16.91	16.814	16.72	16.625	16.514	16.419	16.34	16.229
Grey-headed Gull				2	0	0	3	1	0	0	0	0	0	0	4	9	1	4	110	0	0	2	1	0	0	3	0	22	4	0
Caspian Tern			1	4	2	13	9	0	4	4	3	0	0	2	17	68	6	0	4	0	0	0	5	21	1	2	0	1	1	1
Common Tern	35	0		0	0	0	0	0	0	0	0	0	0	0	0	17	0	7	2	32	0	0	0	0	0	0	0	0	0	0
Swift Tern				0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Little Tern				1	0	0	0	0	0	0	0	0	0	69	7	48	0	22	25	117	64	0	3	0	0	0	0	0	0	0
White-winged Tern			438	0	14	1	5	0	0	0	1	0	0	88	1	0	0	52	50	1	0	22	0	0	0	0	0	0	0	0
Whiskered Tern				43	42	1	0	0	0	0	0	0	0	0	252	0	0	0	0	0	0	0	253	16	0	0	0	0	0	0
Pied Kingfisher	50	39	5	22	25	44	18	37	33	29	36	35	14	23	25	30	25	36	13	23	24	9	25	46	45	26	27	16	19	17
Giant Kingfisher				1	3	3	3	0	0	1	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Malachite Kingfisher	12	12		4	0	3	0	1	0	10	12	3	0	2	3	0	2	1	0	1	0	2	1	2	1	0	2	2	1	2
African Pied Wagtail				0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0
Cape Wagtail				0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0	3	0	0	0	0	0	9	0	2	0
Unidentified Waders			21	0	0	0	0	0	23	0	0	0	0	7	0	53	0	35	1	9	0	98	1	5	0	20	4	142	32	11
Unidentified Terns				0	0	53	96	64	67	78	108	44	12	84	0	0	186	151	7	81	75	12	0	90	204	526	264	116	84	0
Unidentified Ducks				0	0	0	0	0	0	0	0	0	0	23	0	0	8	6	0	0	1	26	0	5	0	0	8	72	29	0
Wood Sandpiper			1																											

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9 SOCIAL

9.1 Introduction

This Section comprises the summary report for social, and provides:

- An overview of the study area, with focus on delineation of homogenous areas;
- For the EWR zones:
    - EcoClassification assessments for social, with supporting evidence;
    - the DRIFT indicators chosen, and reasons therefore;
    - the relationships between the selected indicators and water level or other drivers with referenced, supporting motivations.

9.2 Description of the study area, with the focus on social

9.2.1 Overview of the socio-economic profile

Lake Sibaya is a fresh water lake which is of critical importance to the communities because of their dependence on the goods and services provided by the lake. The communities dependent on the lake include Mseleni to the north of the lake and Mbazwana to the south (Figure 9.1). Communities that live within a 5 km radius were considered to be directly dependent on Lake Sibaya for various goods and services.

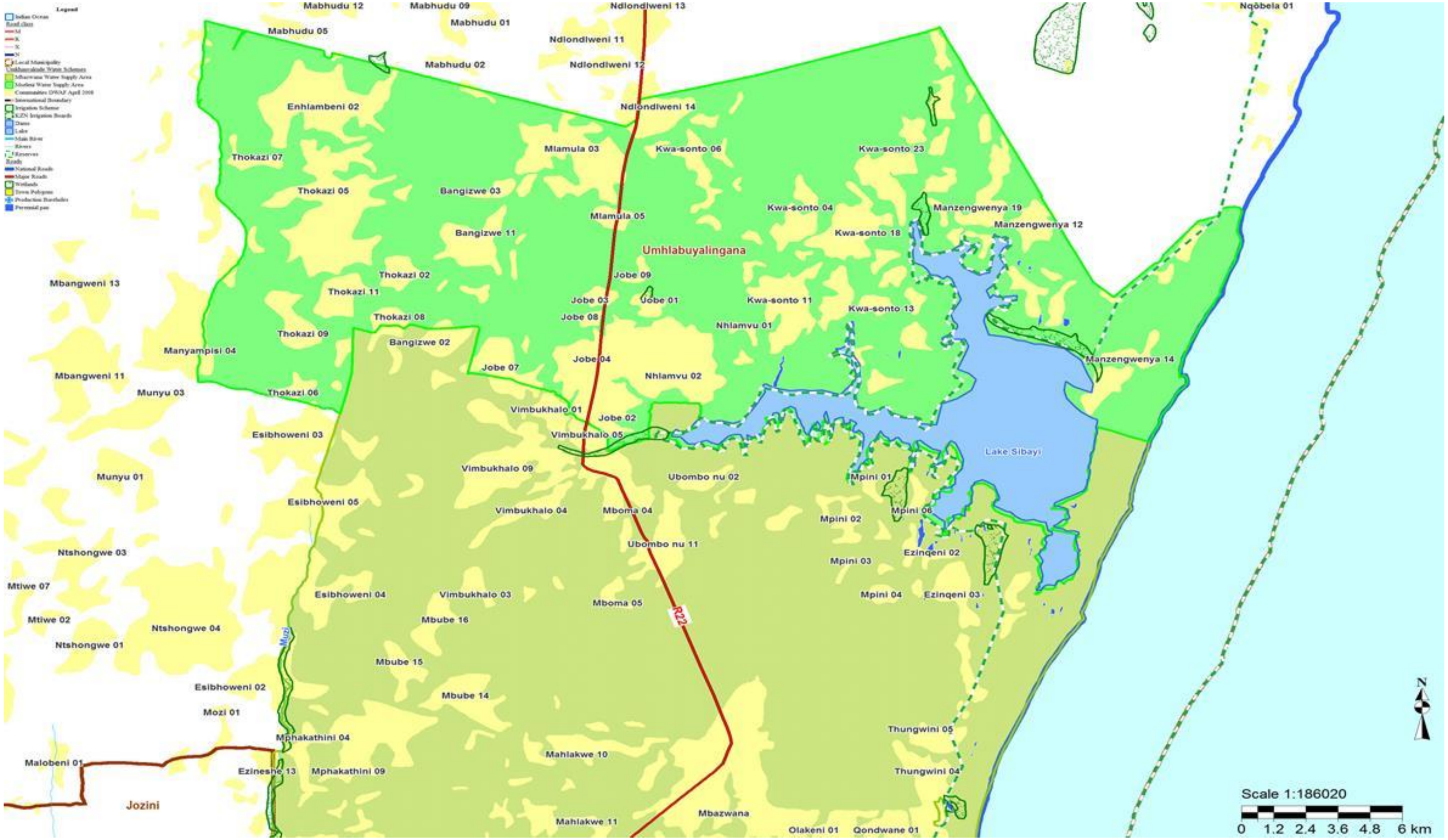


Figure 9.1 Overview of the communities dependent on Lake Sibaya

There are three times more people who are directly dependent on the resources of the Western Basin compared to the other EWR zones of the lake (Table 9.1). The main ecological functions provided by Lake Sibaya, include local and recreational fishing, harvesting of water lilies, sedges and reeds which are a source of food, materials for building and basket weaving and use in reed dances. It is important to note that there are tourists who visit Lake Sibaya and generate economic value add to the local economy.

Table 9.1 Demographic profile of communities directly dependent on the different areas of Lake Sibaya (Statistics SA 2011)

Community	Population	Household	EWR zone
Nhlamvu SP	840	195	Western Basin
Jobe SP	4164	888	
Mboma SP	2004	429	
Sibhoweni SP	1302	270	
Mabaso SP	375	78	
Ezinqeni SP	579	90	
Total Western Basin	**9264**	**1950**	
Umhlabuyalingana NU	369	144	Northern Basin
KwaSonto SP	1332	252	
KwaNsukumbili SP	1266	282	
KwaMjiji SP	426	75	
Total Northern Basin	3393	753	
Ezinqeni SP	579	90	Southern Basin
Thungwini SP	1524	324	
Ubombo SP	423	69	
Total Southern Basin	**2526**	**483**	

Besides the communities that are directly dependent upon the lake, Lake Sibaya is important as a source of domestic water supply to a much bigger area around the lake. According to the All Towns Study report for Mseleni as well as Mbazwana, water is abstracted from the Western Basin as well as the Southern Basin to supply a total population of approximately 44 786 as at 2015. In addition to the current abstraction from the three abstraction works on the lake, there are plans to increase the abstraction from 2.11 million m^3/annum to approximately 3.00 million m^3/annum by 2035.

Therefore from a socio-economic perspective, domestic water use from Lake Sibaya is very important and decline in the ability of the lake to supply water will have a negative impact on the ability and cost of pumping from Lake Sibaya.

9.3 Literature review

9.3.1 Overview

The focus of the literature review was to determine the use of resources and the use of the ecological goods and services from Lake Sibaya.

9.3.2 Domestic water use

Umkhanyakude District Municipality identified Lake Sibaya as a potential source of domestic water supply for the surrounding communities after the operational challenges presented by the use of groundwater. Two water supply systems were developed to abstract water directly from Western Basin and Southern Basin of Lake Sibaya to supply the communities of Mseleni to the north and Mbazwana to the south.

Pontoons were installed to abstract raw water which is then treated and distributed to the local communities. Currently approximately 44,786 people are dependent on the raw water abstraction from the lake (DWS 2015). The RDM plans to increase abstraction from Lake Sibaya to service a population of approximately 61,000 in the future.

9.3.3 Harvesting of resources from the lake

The local communities harvest the root stocks of water lilies as a food source and the leaves of reeds (*Phragmites australis*) and various sedges for roof thatching, construction, gardening as well as basket weaving and the construction of fish traps. In some case the reeds and sedges are used for fuel and in traditional reed dancing ceremonies. Any changes in lake level will have an impact on the abundance of these resources abundance and thereby communities welfare.

9.3.4 Fishing

Seine and fish traps are popular with the local communities for the purposes of subsistence fishing. The extent of commercial fishing is limited and the fish stocks (biomass) should be monitored.

9.3.5 Recreation and Tourism

Lake Sibaya and its surrounds are scenic and have great recreational potential, currently being marketed by the KwaZulu Natal Province. There are some small wilderness-type camps around Lake Sibaya for recreational purposes (Ward and Kyle 1990). Boat trips on the lake are feasible and walking trails are established through the relatively undisturbed shore vegetation. A limited amount of recreational fishing is taking place but the fish are considered to be too small for this to be a larger industry.

9.3.6 Health issues – Bilharzia

Bilharzia is a major health issue in the Mseleni and Mbazwana communities around Lake Sibaya. Bilharzia (*Schistosomiasis*) is an illness caused by a blood fluke *Schistosoma* *haematobium.* The average incidence of bilharzia is 72% (Appleton and Bruton 1979), the high figure being attributed to the reduced abundance of crocodiles and hippos that has acted as a deterrent to human use of the lake. Since many of the water pools in the area are used for washing clothes and bathing the infection rates remain high despite Bilharzia being treatable.

9.4 Identification of indicators

9.4.1 Indicator list for social

A list of social groups/guilds used as indicators in the EWR assessments and reasons for their selection is provided in Table 9.2 while their expected responses to changing water levels are described in Table 9.3.

Table 9.2 Indicators and reasons for their selection

Indicator	Reasons for selection as indicator
Domestic water use	The communities of Mseleni in the north and Mbazwana in the south are dependent on abstracting water from the Lake Sibaya for domestic purposes.
Recreational Use	The lake is used by communities for recreational purposes. Boating and recreational fishing is taking place in the lake.
Fishing	Fishing for household consumption is taking place.
Water lily harvesting	Communities harvest water lilies for consumption. These grow in the shallow waters of the lake.
Reeds and Sedges	Reed (Phragmites) is a wetland plant that has been utilised by man since ancient times. It is a tall, thin, highly productive grass (Poaceae) with an above-ground biomass of up to 30 t/ha-1 y-1. Due to its abundance, it is often cheap and readily available as a raw material. Reeds have been used for centuries as a fodder plant in summer, and the stems have traditionally been harvested in winter as a raw material for crafts, mats, and for construction materials including roofing. Reeds grows mostly in fresh water and is found on the shores of Lake Sibaya.
Health aspects	Snails found around the lake carrying bilharzia has a negative impact on the social welfare of the communities dependent on Lake Sibaya.
Cattle Watering	Cattle are very important in KwaZulu Natal including the areas surrounding the Lake. The cattle are watered at the Lake.

Table 9.3 List of social indicators and their predicted direction of response to water level changes

Indicator	Definition	Predicted change
Domestic water use	Abstraction of raw water from the Lake for use domestic purposes by the communities	Decrease in lake level will result in a reduction in domestic water use. This is because of the increases in cost due to increased pumping head as well as increased maintenance costs due to negative pump performance.
Recreational	This includes recreational fishing,	Any decrease in the lake level is likely to

Indicator	Definition	Predicted change
Use	boating; etc.	expose the shoreline making it more difficult to launch boats.
Fishing	Subsistence fishing by local communities	This is a linked indicator. A decline in the fish biomass will reduce the fishing by the communities.
Water lily harvesting	The roots of water lilies are used to produce flour out of dried roots by pounding them. The young leaves and flower buds are sometimes eaten as vegetables.	Changes in water lily abundance may result are dependent on the lake volume and rate of change of water level in the lake.
Reeds and Sedges	Reeds are used for roofing and erecting gardens while the sedges are used to weave baskets and nets used for fishing.	Changes in the abundance of megagraminoids are dependent on lake volume and rate of change of water level in the lake.
Health aspects - Bilharzia	Snails carrying Bilharzia are common.	Access to the lake shores as well as the lake volumes impact on the breeding of the snails carrying bilharzia.
Cattle Watering	Cattle watering.	A decline in the lake volume will have a negative impact on the watering of cattle by the communities.

9.4.2 Description and location of indicators

9.4.2.1 Name: Domestic water use

Location:	Western Arm, Southern Basin
Representative indicator:	Domestic water use
Other characteristics:	Water quality must be maintained
Flow-related concerns:	Rate of change in the lake level, lake volume

9.4.2.2 Name: Recreational Use

Location:	Main Basin, Southern Basin, Southwestern Basin, Western Arm and Northern Arm
Representative indicator:	Recreational use
Other characteristics:	Quality of the water, Contamination
Flow-related concerns:	Rate of change of water levels, lake volume

9.4.2.3 Name: Fishing

Location:	Southern Basin, Western Arm and Northern Arm
Representative indicator:	Fish Biomass
Other characteristics:	None
Flow-related concerns:	Area between 1 and 1.5 m deep

9.4.2.4 Name: Harvesting of Water Lilies

Location:	Main Basin, Southern Basin, Western Basin and Northern Basin
Representative indicator:	Submerged rooted vegetation
Other characteristics:	Emergent Macrophytes
Flow-related concerns:	Area below 0.65 m; perimeter; rate of change in water level

9.4.2.5 Name: Harvesting of reeds and sedges

Location:	Western Arm, Northern Arm, Southwestern Basin; and Southern Basin
Representative indicator:	Submerged rooted vegetation
Other characteristics:	None
Flow-related concerns:	Area 0 to 7 m deep, rate of change of water level

9.4.2.6 Name: Health (Bilharzia)

Location:	Western Arm; Southern Basin; Southwestern Basin; Northern Arm
Representative indicator:	Bilharzia
Other characteristics:	Emergent Macrophytes
Flow-related concerns:	Area 0 to 0.3 m deep

9.4.2.7 Name: Cattle Watering

Location:	Western Arm, Northern Arm and Southern Basin
Representative indicator:	Volume of water in the lake
Other characteristics:	None
Flow-related concerns:	Rate of change of water levels

9.4.3 Linked indicators

Motivations for linked indicators are provided below in Table 9.4.

Table 9.4 Linked indicators and motivation

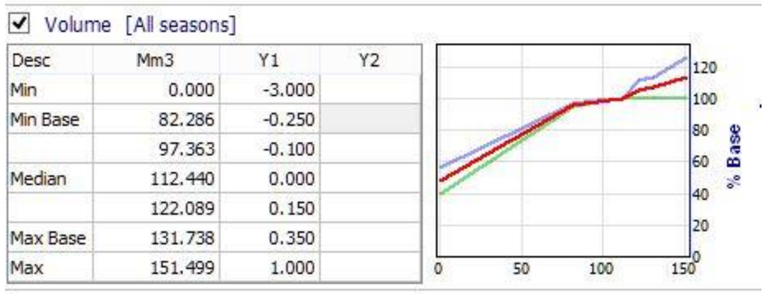
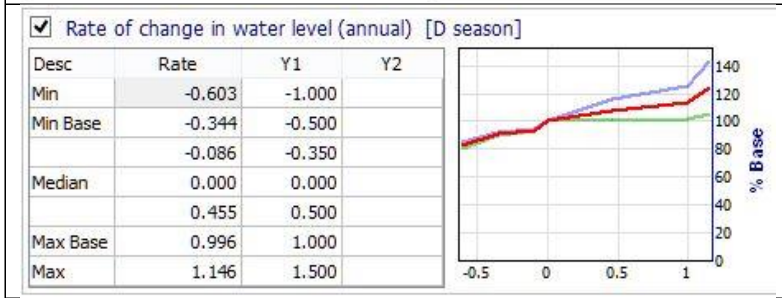
Indicator	Linked indicator	Motivation
Domestic water use	Lake volume, rate of change of lake levels.	The domestic water use is driven by the availability (volume) of water in the lake. In addition it is driven by the water level in the lake. As the lake volume increases the energy costs and pumping capacity reduces.
Recreational Use	Lake volume	The domestic water use is driven by the volume of water in the lake as well as the

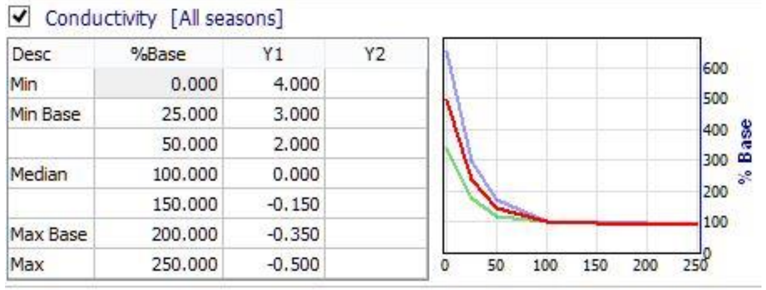
Indicator	Linked indicator	Motivation
		quality of the water.
Fishing	Fish biomass	For the communities fishing is driven by their availability and abundance.
Water lily harvesting	Submerged vegetation	The abundance of submerged vegetation determines supply of lilies.
Reeds and Sedges	Emergent vegetation	The abundance of emergent vegetation determines supply of reeds and sedges.
Health aspects	Bilharzia	Bilharzia is a great cost to community well being
Cattle watering	Lake volume	Supply determined by lake volume.

9.5 Motivations for Response Curves

9.5.1 Domestic water use

9.5.1.1 Western arm

<table>
<tr><td colspan="2">Domestic water use: Western Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Volume [All seasons]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.000</td><td></td></tr>
<tr><td>Min Base</td><td>82.286</td><td>-0.250</td><td></td></tr>
<tr><td></td><td>97.363</td><td>-0.100</td><td></td></tr>
<tr><td>Median</td><td>112.440</td><td>0.000</td><td></td></tr>
<tr><td></td><td>122.089</td><td>0.150</td><td></td></tr>
<tr><td>Max Base</td><td>131.738</td><td>0.350</td><td></td></tr>
<tr><td>Max</td><td>151.499</td><td>1.000</td><td></td></tr>
</table>
</td><td>As the volume of water or lake level rises - communities will increase their dependence on water use. Abstractions from the lake for domestic purposes will increase. However as the lake levels decrease, the difficulty to abstract water increases. This will in turn decrease domestic water use from the lake. Mseleni is dependent on the western arm for nearly 80% of its domestic water use.</td><td>High</td></tr>
<tr><td>
☑ Rate of change in water level (annual) [D season]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>-0.350</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>1.000</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>1.500</td><td></td></tr>
</table>
</td><td>The rate of change in water level has an impact on the operation of the pumps installed in the lake for domestic water abstraction. As the lake levels decline there is major effort in moving the pontoons to where the level declines to. The lower the rate of change in the levels of the lake the higher the use of the lake for domestic purposes. Therefore abstraction of domestic water use closely follows the lake level and therefore the rate of change in the water level.</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Domestic water use: Western Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Conductivity [All seasons]
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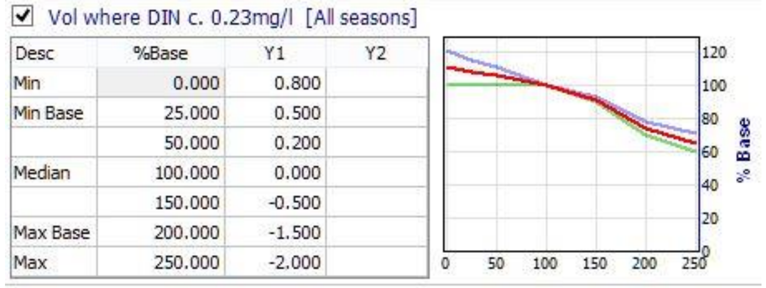
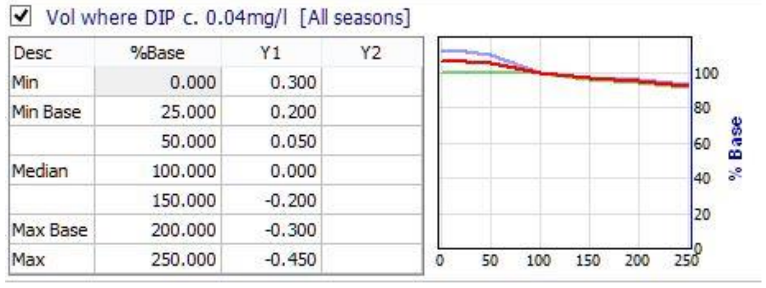
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>4.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>3.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>2.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.150</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-0.350</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-0.500</td><td></td></tr>
</table>

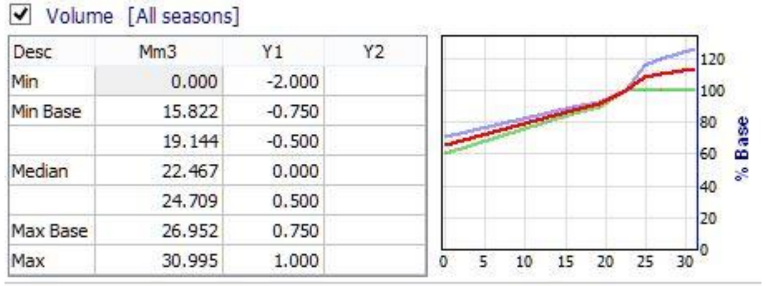
</td><td>Conductivity is used to measure the concentration of dissolved solids which have been ionized in water. Significant change, whether it is due to natural flooding, evaporation or reduction in the lake level pollution can be very detrimental to water quality and therefore domestic use of the water. The higher the conductivity the more need to treat the water. This reduces the potential for domestic use as the communities are in most cases not treating the water except chlorination. The converse is true that as the concentration of the dissolved solids is reduced there is a high need for the use of the lake water for domestic purposes.</td><td>Moderate</td></tr>
<tr><td>

☑ Vol where DIN c. 0.23mg/l [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.800</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-2.000</td><td></td></tr>
</table>

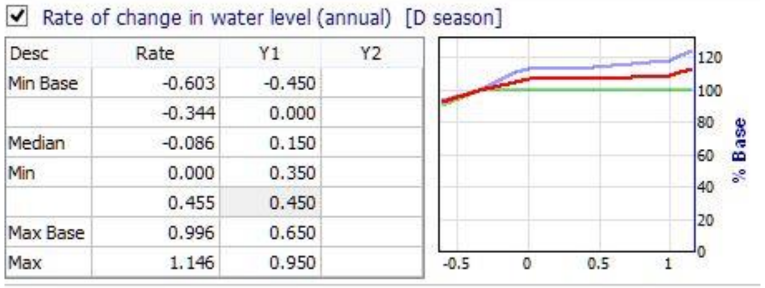
</td><td>Nitrates in water indicate pollution of the water. Nitrate concentration levels are due primarily to agricultural practices and leaching from pit latrines. Any increase in the nitrates as nitrites will impact on the domestic water use from the Western Basin of the lake, unless it is treated (which is a significant cost to domestic users). This will reduce the extent of domestic use although this will not be significant because of treatment options. The treatment can be expensive and therefore reduce the volume of water abstraction from the lake.</td><td>Moderate</td></tr>
<tr><td>

☑ Vol where DIP c. 0.04mg/l [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.300</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.200</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.050</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-0.300</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-0.450</td><td></td></tr>
</table>

</td><td>The natural levels of phosphate acceptable for drinking water purposes should not be higher than 0.05 mg/l. Any major increases in the levels of phosphates will decrease the domestic use because of the need to treat the water. This becomes costly. The lower the phosphate levels the more likely use of the water for domestic use.</td><td>Moderate</td></tr>
</table>

9.5.1.2 Southern Basin

Domestic water use: Southern Basin		
Linked indicator response curve	Explanation	Confidence

<table>
<tr><td colspan="2">Domestic water use: Southern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Volume [All seasons]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>15.822</td><td>-0.750</td><td></td></tr>
<tr><td></td><td>19.144</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>22.467</td><td>0.000</td><td></td></tr>
<tr><td></td><td>24.709</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>26.952</td><td>0.750</td><td></td></tr>
<tr><td>Max</td><td>30.995</td><td>1.000</td><td></td></tr>
</table>

</td><td>As the volume of water or lake level rises - communities will increase their dependence on water use. Abstractions from the lake for domestic purposes will increase. However as the lake levels decrease, the difficulty to abstract increases. This will in turn decrease domestic water use from the lake. Mbazwana is dependent on the waters of Southern Basin for nearly 95% of its domestic water use.</td><td>High</td></tr>
<tr><td>

☑ Rate of change in water level (annual) [D season]
<table>
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<tr><td>Min</td><td>0.000</td><td>0.350</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.450</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>0.650</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>0.950</td><td></td></tr>
</table>

</td><td>The rate of change in water level has an impact on the operation of the pumps installed in the lake for domestic water abstraction. As the lake levels decline major effort is required to moving the pontoons to the lowered water levels. The lower the rate of change in the levels of the lake the higher the use of the lake for domestic purposes. Therefore abstraction of domestic water use closely follows the lake level and therefore the rate of change in the water level.</td><td>High</td></tr>
<tr><td>

☑ Conductivity [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.950</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.750</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.150</td><td></td></tr>
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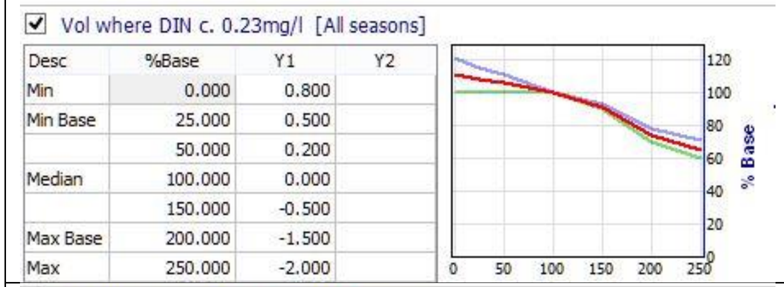
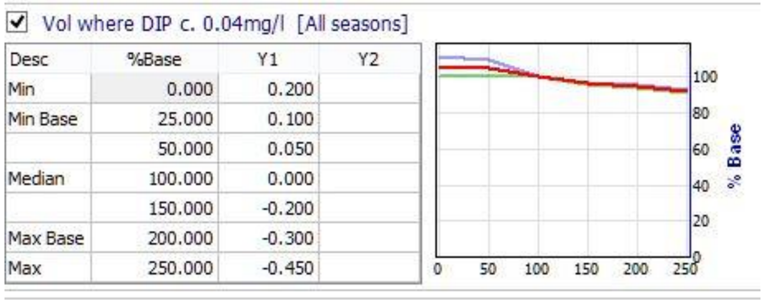
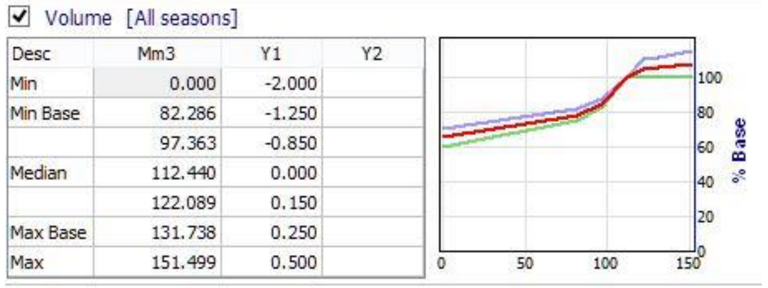
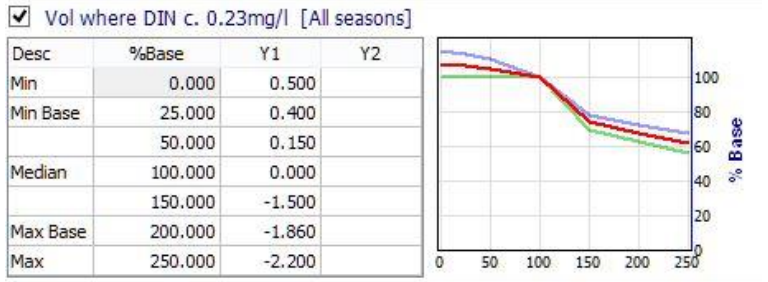
</table>

<table>
<tr><td colspan="2">Domestic water use: Southern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Vol where DIN c. 0.23mg/l [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.800</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-2.000</td><td></td></tr>
</table>
</td><td>Nitrates in water indicate pollution of the water. Nitrate concentration levels are due to agricultural practices and leaching from pit latrines. Any increase in the nitrates as nitrites will impact on the domestic water use from the Southern Basin of the lake, unless it is treated (which is a significant cost to domestic users). This will reduce the extent of domestic use although this will not be significant because of treatment options. The treatment can be expensive and therefore reduce the volume of water abstraction from the lake.</td><td>Moderate</td></tr>
<tr><td>
☑ Vol where DIP c. 0.04mg/l [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.200</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.100</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.050</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-0.300</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-0.450</td><td></td></tr>
</table>
</td><td>The natural levels of phosphate acceptable for drinking water purposes should not be higher than 0.05 mg/l. Any major increases in the levels of phosphates will decrease the domestic use because of the need to treat the water. This becomes costly. The lower the phosphate levels the more likely use of the water for domestic use.</td><td>Moderate</td></tr>
</table>

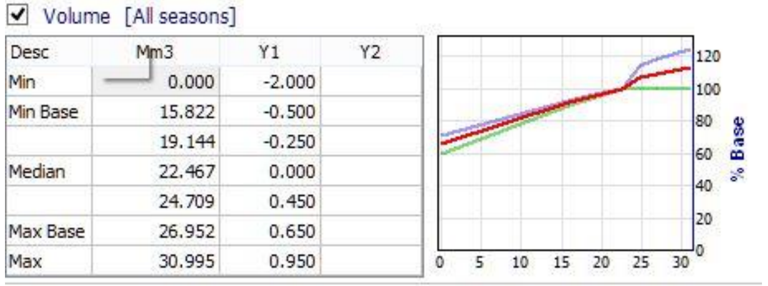
9.5.2 Recreational Use

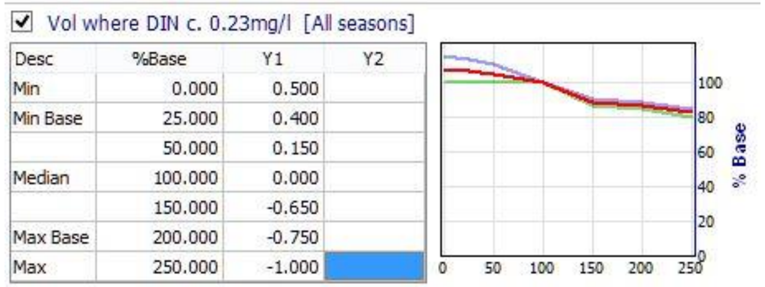
9.5.2.1 Western Arm

Recreational use: Western Arm		
Linked indicator response curve	Explanation	Confidence

<table>
<tr><td colspan="2">Recreational use: Western Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Volume [All seasons]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>82.286</td><td>-1.250</td><td></td></tr>
<tr><td></td><td>97.363</td><td>-0.850</td><td></td></tr>
<tr><td>Median</td><td>112.440</td><td>0.000</td><td></td></tr>
<tr><td></td><td>122.089</td><td>0.150</td><td></td></tr>
<tr><td>Max Base</td><td>131.738</td><td>0.250</td><td></td></tr>
<tr><td>Max</td><td>151.499</td><td>0.500</td><td></td></tr>
</table>
</td><td>Lake Sibaya is used for recreational fishing and swimming (but this is limited because of hippos & crocodiles), as well as birding. Water-based recreational activities increase as the water level rises, whereas these activities decline as the levels of the lake decrease. This is a function of the volume of the lake. However as the lake levels have declined significantly the recreational use of the Western Basin has declined significantly.</td><td>High</td></tr>
<tr><td>
☑ Vol where DIN c. 0.23mg/l [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.400</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.150</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.860</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-2.200</td><td></td></tr>
</table>
</td><td>Although Lake Sibaya has an abundance of coastal resources, it is also susceptible to pollution and siltation due to human influences and the *Endothecia* mosses that grow around the lake. The increases in nutrient levels will affect the recreational use of the lake.</td><td>Moderate</td></tr>
</table>

9.5.2.2 *Southern Basin*

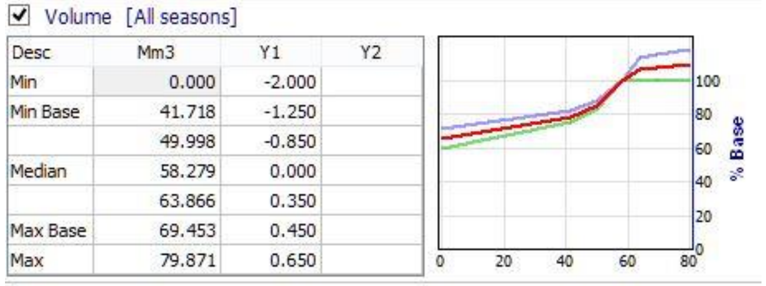
<table>
<tr><td colspan="2">Recreational use: Southern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Volume [All seasons]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>15.822</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>19.144</td><td>-0.250</td><td></td></tr>
<tr><td>Median</td><td>22.467</td><td>0.000</td><td></td></tr>
<tr><td></td><td>24.709</td><td>0.450</td><td></td></tr>
<tr><td>Max Base</td><td>26.952</td><td>0.650</td><td></td></tr>
<tr><td>Max</td><td>30.995</td><td>0.950</td><td></td></tr>
</table>
</td><td>Lake Sibaya is used for recreational fishing and swimming (but this is limited because of hippos & crocodiles), as well as birding. Water-based recreational activities increase as the water level rises, whereas these activities decline as the levels of the lake decrease. This is a function of the volume of the lake. However as the lake levels have declined significantly the recreational use of the Western Basin has declined significantly.</td><td>High</td></tr>
</table>

Recreational use: Southern Basin		
Linked indicator response curve	Explanation	Confidence
	Although Lake Sibaya has an abundance of coastal resources, it is also susceptible to pollution and siltation due to human influences and the *endothecia* mosses that grow around the lake. The increases in nutrient levels may affect the recreational use of the lake.	Moderate

☑ Vol where DIN c. 0.23mg/l [All seasons]

Desc	%Base	Y1	Y2
Min	0.000	0.500	
Min Base	25.000	0.400	
	50.000	0.150	
Median	100.000	0.000	
	150.000	-0.650	
Max Base	200.000	-0.750	
Max	250.000	-1.000	

9.5.2.3 Northern Arm

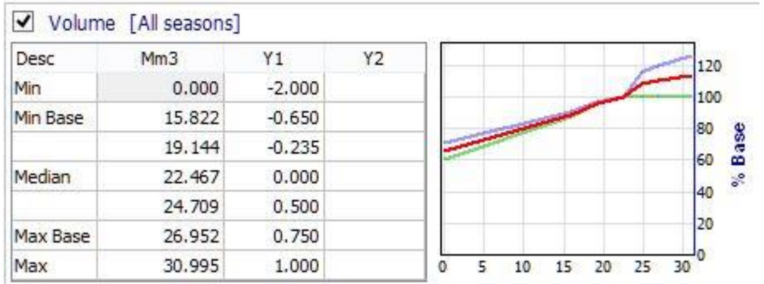
Recreational use: Northern Arm		
Linked indicator response curve	Explanation	Confidence
	Lake Sibaya is used used for recreational fishing and swimming (but this is limited because of hippos & crocodiles) as well as birding. Water-based recreational activities increase as the water level rises, whereas these activities decline as the levels of the lake decrease. This is a function of the volume of the lake. However as the lake levels have declined significantly the recreational use of the Western Basin has declined significantly.	High

☑ Volume [All seasons]

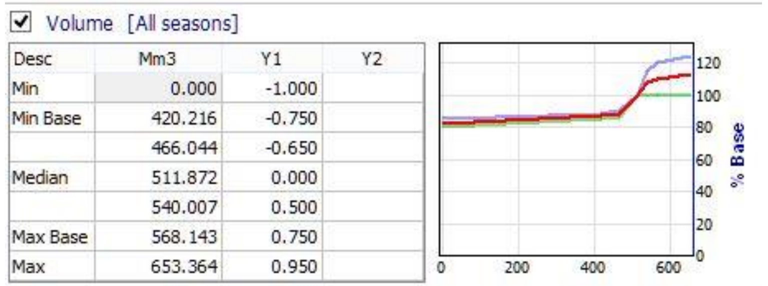
Desc	Mm3	Y1	Y2
Min	0.000	-2.000	
Min Base	41.718	-1.250	
	49.998	-0.850	
Median	58.279	0.000	
	63.866	0.350	
Max Base	69.453	0.450	
Max	79.871	0.650	

9.5.2.4 Southwestern Basin

Recreational use: Southwestern Basin		
Linked indicator response curve	Explanation	Confidence

<table>
<tr><td colspan="2">Recreational use: Southwestern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Volume [All seasons]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>15.822</td><td>-0.650</td><td></td></tr>
<tr><td></td><td>19.144</td><td>-0.235</td><td></td></tr>
<tr><td>Median</td><td>22.467</td><td>0.000</td><td></td></tr>
<tr><td></td><td>24.709</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>26.952</td><td>0.750</td><td></td></tr>
<tr><td>Max</td><td>30.995</td><td>1.000</td><td></td></tr>
</table>
</td><td>Lake Sibaya is used for recreational fishing, swimming (this is limited because of hippos & crocodiles) as well as birding. Water-based recreational activities increase as the water level rises, whereas these activities decline as the levels of the lake decrease. This is a function of the volume of the lake. However as the lake levels have declined significantly the recreational use of the Western Basin has declined significantly.</td><td>High</td></tr>
</table>

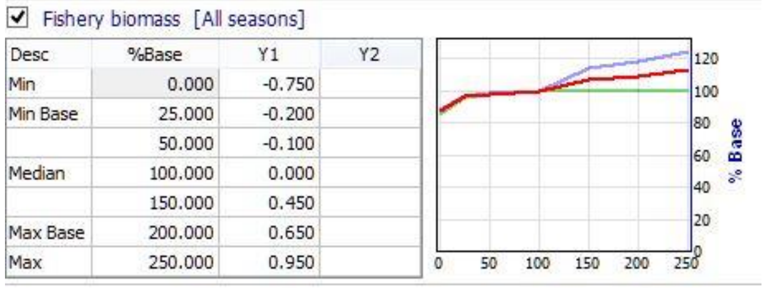
9.5.2.5 *Main Basin*

<table>
<tr><td colspan="2">Recreational use: Main Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Volume [All seasons]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>420.216</td><td>-0.750</td><td></td></tr>
<tr><td></td><td>466.044</td><td>-0.650</td><td></td></tr>
<tr><td>Median</td><td>511.872</td><td>0.000</td><td></td></tr>
<tr><td></td><td>540.007</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>568.143</td><td>0.750</td><td></td></tr>
<tr><td>Max</td><td>653.364</td><td>0.950</td><td></td></tr>
</table>
</td><td>Lake Sibaya is used used for recreational fishing and swimming (this is limited because of hippos & crocodiles) as well as birding. Water-based recreational activities increase as the water level rises, whereas these activities decline as the levels of the lake decrease. This is a function of the volume of the lake. However as the lake levels have declined significantly the recreational use of the Western Basin has declined significantly.</td><td>High</td></tr>
</table>

9.5.3 Fishing

9.5.3.1 *Western Arm*

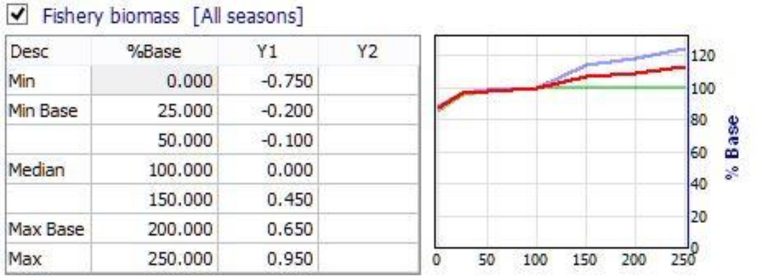
<table>
<tr><td colspan="2">Fishing: Western Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
</table>

Fishing: Western Arm		
Linked indicator response curve	Explanation	Confidence
	There are two aspects to fishing in Lake Sibaya, recreational fishing and fishing for household consumption. The major driver is the fish biomass that has been used to determine the likely impact on the availability of fish stock to the communities. As the lake levels have declined, the fish abundance has declined and continues to decline. During periods when the lake levels rose, there has been a significant increase in fishing for household consumption. However fishing for household consumption has declined.	High

☑ Fishery biomass [All seasons]

Desc	%Base	Y1	Y2
Min	0.000	-0.750	
Min Base	25.000	-0.200	
	50.000	-0.100	
Median	100.000	0.000	
	150.000	0.450	
Max Base	200.000	0.650	
Max	250.000	0.950	

9.5.3.2 Southern Basin

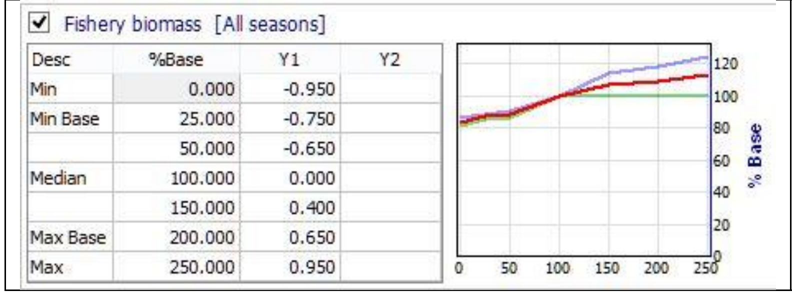
Fishing: Southern Basin		
Linked indicator response curve	Explanation	Confidence
	There are two aspects to fishing in Lake Sibaya, recreational fishing and fishing for household consumption. The major driver is the fish biomass that has been used to determine the likely impact on the availability of fish stock to the communities. As the lake levels have declined, the fish abundance has declined and continues to decline. During periods when the lake levels rose, there has been a significant increase in fishing for household consumption. However fishing for household consumption has declined.	High

☑ Fishery biomass [All seasons]

Desc	%Base	Y1	Y2
Min	0.000	-0.750	
Min Base	25.000	-0.200	
	50.000	-0.100	
Median	100.000	0.000	
	150.000	0.450	
Max Base	200.000	0.650	
Max	250.000	0.950	

9.5.3.3 Northern Arm

Fishing: Northern Arm		
Linked indicator response curve	Explanation	Confidence

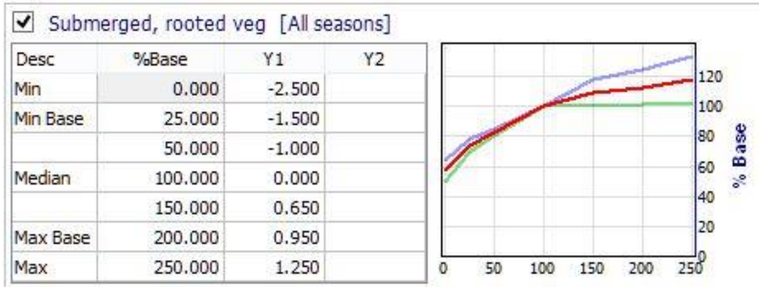
Fishing: Northern Arm		
Linked indicator response curve	Explanation	Confidence
	There are two aspects to fishing in Lake Sibaya, recreational fishing and fishing for household consumption. The availability of fish has been assumed to be the fish biomass that has been used to determine the likely impact on the availability of fish stock to the communities. As the lake levels have declined, the fish abundance has declined and continues to decline. During periods when the lake levels rose, there has been a significant increase in fishing for household consumption. However fishing for household consumption has declined.	High

☑ Fishery biomass [All seasons]

Desc	%Base	Y1	Y2
Min	0.000	-0.950	
Min Base	25.000	-0.750	
	50.000	-0.650	
Median	100.000	0.000	
	150.000	0.400	
Max Base	200.000	0.650	
Max	250.000	0.950	

9.5.4 Water Lilies Harvesting

9.5.4.1 Western Arm

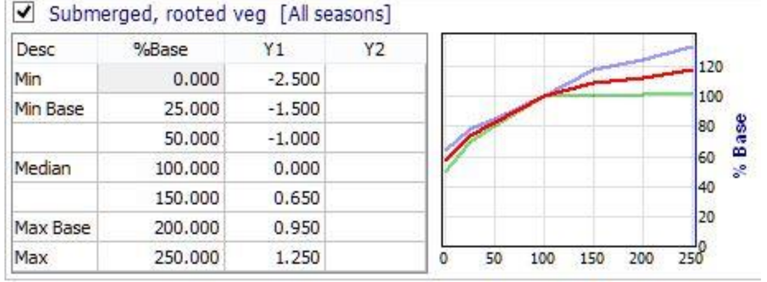
Water lilies harvesting – Western Arm		
Linked indicator response curve	Explanation	Confidence
	The dired roots of water lilies are used to produce flour by pounding them. The young leaves and flower buds are sometimes eaten as vegetables. Any increase in the submerged root vegetation increases the production or abundance of water lilies particularly in the wetlands as well as the shallows shows of the Western Basin. The use of the water lilies increases with abundance and therefore follows the abundance of the submerged root vegetation.	High

☑ Submerged, rooted veg [All seasons]

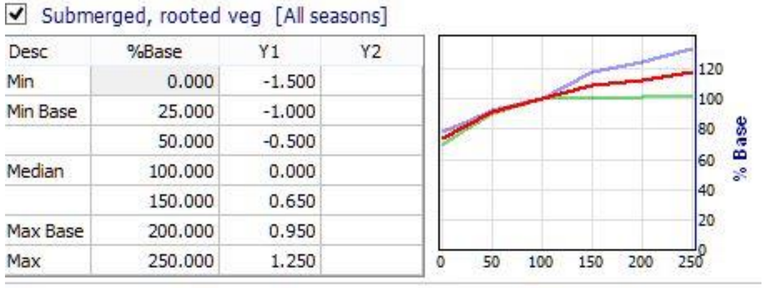
Desc	%Base	Y1	Y2
Min	0.000	-2.500	
Min Base	25.000	-1.500	
	50.000	-1.000	
Median	100.000	0.000	
	150.000	0.650	
Max Base	200.000	0.950	
Max	250.000	1.250	

9.5.4.2 Northern Arm

Water lilies harvesting – Northern Arm		
Linked indicator response curve	Explanation	Confidence

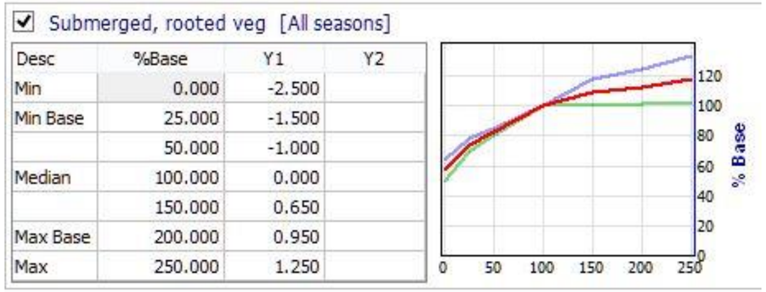
<table>
<tr><td colspan="2">Water lilies harvesting – Northern Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Submerged, rooted veg [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.650</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.950</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.250</td><td></td></tr>
</table>
</td><td>The dried roots of water lilies are used to produce flour by pounding them. The young leaves and flower buds are sometimes eaten as vegetables. Any increase in the submerged root vegetation increases the production or abundance of water lilies particularly in the wetlands as well as the shallows shows of the northern basin. The use of the water lilies increases with abundance and therefore follows the abundance of the submerged root vegetation.</td><td>High</td></tr>
</table>

9.5.4.3 Southwestern Basin

<table>
<tr><td colspan="2">Water lilies harvesting – Southwestern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Submerged, rooted veg [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.650</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.950</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.250</td><td></td></tr>
</table>
</td><td>The roots of water lilies are used to produce flour out of dried roots by pounding them. The young leaves and flower buds are sometimes eaten as vegetables. Any increase in the submerged root vegetation increases the production of water lilies particularly in the wetlands as well as the shallows shows of the Southwestern Basin. The use of the water lilies increases with abundance and therefore follows the abundance of the submerged root vegetation.</td><td>High</td></tr>
</table>

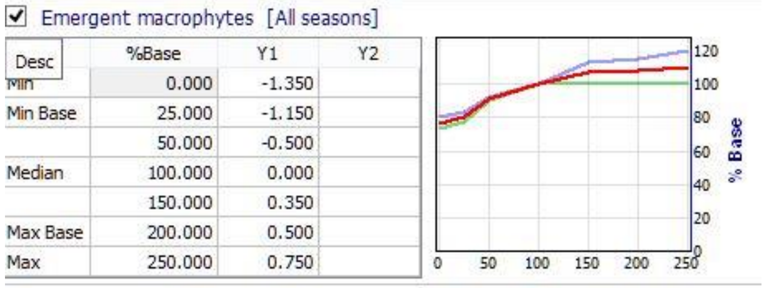
9.5.4.4 Southern Basin

<table>
<tr><td colspan="2">Water lilies harvesting – Southern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
</table>

<table>
<tr><td colspan="2">Water lilies harvesting – Southern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Submerged, rooted veg [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.650</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.950</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.250</td><td></td></tr>
</table>
</td><td>The dried roots of water lilies are used to produce flour by pounding them. The young leaves and flower buds are sometimes eaten as vegetables. Any increase in the submerged root vegetation increases the production of water lilies particularly in the wetlands as well as the shallows shows of the Southern Basin. The use of the water lilies increases with abundance and therefore follows the abundance of the submerged root vegetation.</td><td>High</td></tr>
</table>

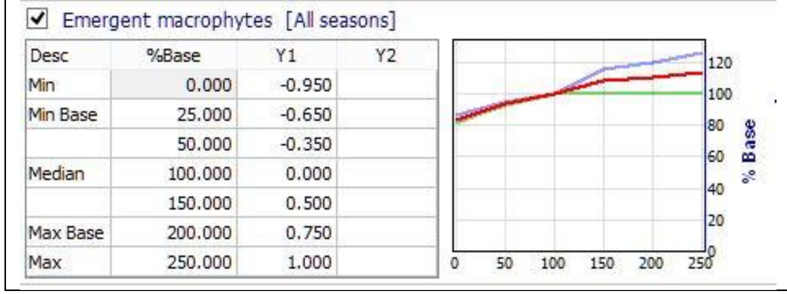
9.5.5 Harvesting of Reeds and Sedges

9.5.5.1 Western Arm

<table>
<tr><td colspan="2">Reeds and Sedges harvesting – Western Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Emergent macrophytes [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.350</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.150</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.350</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.750</td><td></td></tr>
</table>
</td><td>The reeds and sedges are used for roofing and basket weaving. Any increase in the emergent macrophytes increases the production of reeds and sedges particularly in the wetlands as well as the shallow shows of the Western Basin. The use of the reeds and sedges increases with abundance and therefore follows the abundance of the emergent macrophytes. In addition to the abundance of the macrophytes, the quality of the reeds also determine their use which ranges from roof thatching to basket weaving and fish traps</td><td>High</td></tr>
</table>

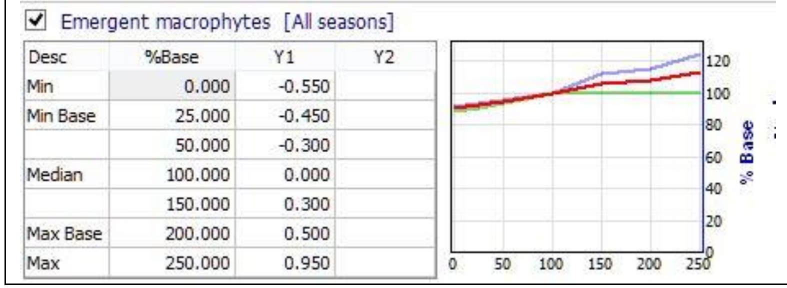
9.5.5.2 Southern Basin

<table>
<tr><td colspan="2">Reeds and Sedges harvesting – Southern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
</table>

<table>
<tr><td colspan="2">Reeds and Sedges harvesting – Southern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Emergent macrophytes [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.950</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.650</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.350</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.750</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.000</td><td></td></tr>
</table>

</td><td>The reeds and sedges are used for roofing and basket weaving. Any increase in the emergent macrophytes increases the production of reeds and sedges particularly in the wetlands as well as the shallow shows of the Southern Basin. The use of the reeds and sedges increases with abundance and therefore follows the abundance of the emergent macrophytes. In addition to the abundance of the macrophytes, the quality of the reeds also determine their use which ranges from roof thatching to basket weaving and fish traps</td><td>High</td></tr>
</table>

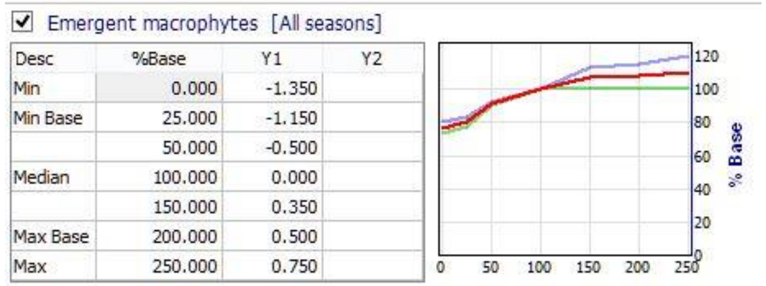
9.5.5.3 *Southwestern Arm*

<table>
<tr><td colspan="2">Reeds and Sedges harvesting – Southwestern Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>

☑ Emergent macrophytes [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.550</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.450</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.950</td><td></td></tr>
</table>

</td><td>The reeds and sedges are used for roofing and basket weaving. Any increase in the emergent macrophytes increases the production of reeds and sedges particularly in the wetlands as well as the shallow shows of the Southwestern Basin. The use of the reeds and sedges increases with abundance and therefore follows the abundance of the emergent macrophytes. In addition to the abundance of the macrophytes, the quality of the reeds also determine their use which ranges from roof thatching to basket weaving and fish traps</td><td>High</td></tr>
</table>

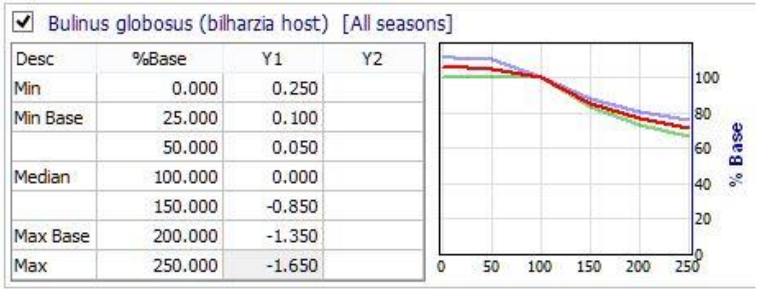
9.5.5.4 *Northern Arm*

<table>
<tr><td colspan="2">Reeds and Sedges harvesting – Northern Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
</table>

<table>
<tr><td colspan="2">Reeds and Sedges harvesting – Northern Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Emergent macrophytes [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.350</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.150</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.350</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.750</td><td></td></tr>
</table>
</td><td>The reeds and sedges are used for roofing and basket weaving. Any increase in the emergent macrophytes increases the production of reeds and sedges particularly in the wetlands as well as the shallow shows of the northern basin. The use of the reeds and sedges increases with abundance and therefore follows the abundance of the emergent macrophytes. In addition to the abundance of the macrophytes, the quality of the reeds also determine their use which ranges from roof thatching to basket weaving and fish traps</td><td>High</td></tr>
</table>

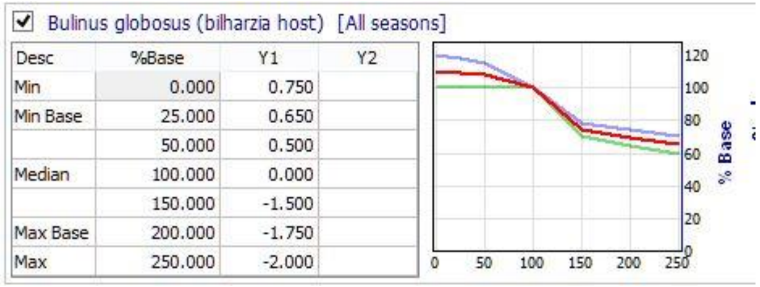
9.5.6 Health (Bilharzia

9.5.6.1 *Western Arm*

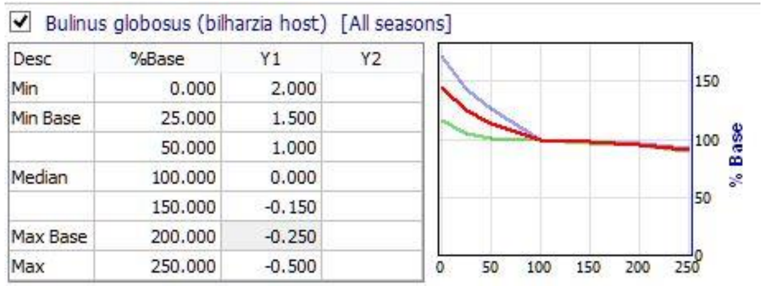
<table>
<tr><td colspan="2">Health (Bilharzia) – Western Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Bulinus globosus (bilharzia host) [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.250</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.100</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.050</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.850</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.350</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-1.650</td><td></td></tr>
</table>
</td><td>Infection occurs when skin comes in contact with contaminated freshwater in which certain types of snails that carry schistosomes occur. These are found in the shores of Lake Sibaya. The parasite leaves the snail and enters the water where the parasites then can penetrate the skin of persons who are wading, swimming, bathing, or washing in contaminated water. The parasites can also enter through the lining of mouth or intestinal tract of people who drink untreated water. Any increase in the bilhrazia results in an increase in health problems particularly the Western Basin which people access for swimming, fishing, and harvesting of reeds and sedges. Accessibility to the shores of lake plays a significant roles in increasing cases of bilharzia as well as the lake levels.</td><td>High</td></tr>
</table>

9.5.6.2 *Southwestern Basin*

<table>
<tr><td colspan="2">Health (Bilharzia) – Southwestern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
</table>

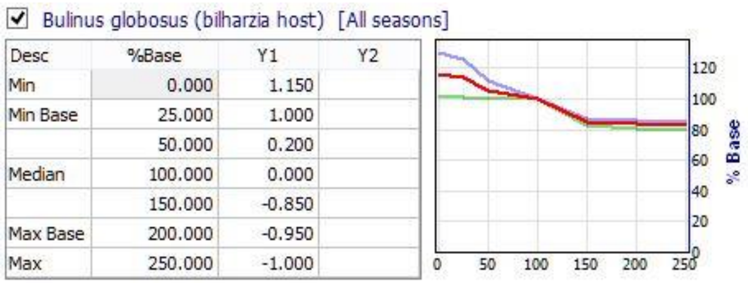
<table>
<tr><td colspan="2">Health (Bilharzia) – Southwestern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Bulinus globosus (bilharzia host) [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.750</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.650</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.750</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-2.000</td><td></td></tr>
</table>
</td><td>Infection occurs when skin comes in contact with contaminated freshwater in which certain types of snails that carry schistosomes occur. These are found in the shores of Lake Sibaya. The parasite leaves the snail and enters the water where the parasites then can penetrate the skin of persons who are wading, swimming, bathing, or washing in contaminated water. The parasites can also enter through the lining of mouth or intestinal tract of people who drink untreated water. Any increase in the bilhrazia results in an increase in health problems particularly the Southwestern Basin which people access for swimming, fishing, and harvesting of reeds and sedges. Accessibility to the shores of lake plays a significant roles in increasing cases of bilharzia as well as the lake levels.</td><td>High</td></tr>
</table>

9.5.6.3 Southern Basin

<table>
<tr><td colspan="2">Health (Bilharzia) – Southern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Bulinus globosus (bilharzia host) [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>2.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.150</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-0.250</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-0.500</td><td></td></tr>
</table>
</td><td>Infection occurs when skin comes in contact with contaminated freshwater in which certain types of snails that carry schistosomes occur. These are found in the shores of Lake Sibaya. The parasite leaves the snail and enters the water where the parasites then can penetrate the skin of persons who are wading, swimming, bathing, or washing in contaminated water. The parasites can also enter through the lining of mouth or intestinal tract of people who drink untreated water. Any increase in the bilhrazia results in an increase in health problems. The limited access to the shores of the Southern Basin which people access for swimming, fishing, and harvesting of reeds and sedges indicates that Bilharzia is not as prevalent compared to other basins. Accessibility to the shores of lake plays a significant roles in increasing cases of bilharzia as well as the lake levels.</td><td>High</td></tr>
</table>

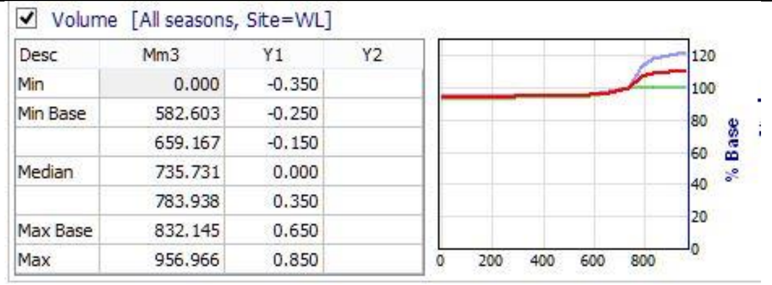
9.5.6.4 Northern Arm

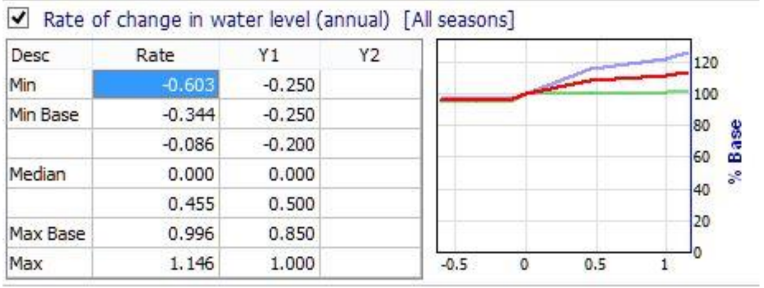
Health (Bilharzia) – Northern Arm		
Linked indicator response curve	Explanation	Confidence

<table>
<tr><td colspan="2">Health (Bilharzia) – Northern Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Bulinus globosus (bilharzia host) [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.150</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.850</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-0.950</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-1.000</td><td></td></tr>
</table>
</td><td>Infection occurs when skin comes in contact with contaminated freshwater in which certain types of snails that carry schistosomes occur. These are found in the shores of Lake Sibaya. The parasite leaves the snail and enters the water where the parasites then can penetrate the skin of persons who are wading, swimming, bathing, or washing in contaminated water. The parasites can also enter through the lining of mouth or intestinal tract of people who drink untreated water. Any increase in the bilharzia results in an increase in health problems particularly the northern basin which people access for swimming, fishing, and harvesting of reeds and sedges. Accessibility to the shores of lake plays a significant role in increasing cases of bilharzia as well as the lake levels.</td><td>High</td></tr>
</table>

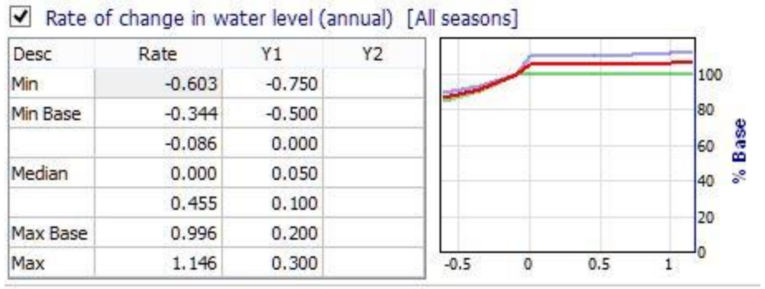
9.5.7 Cattle watering

9.5.7.1 Western Arm

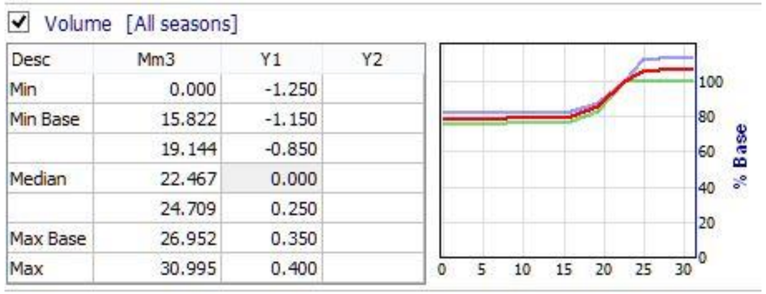
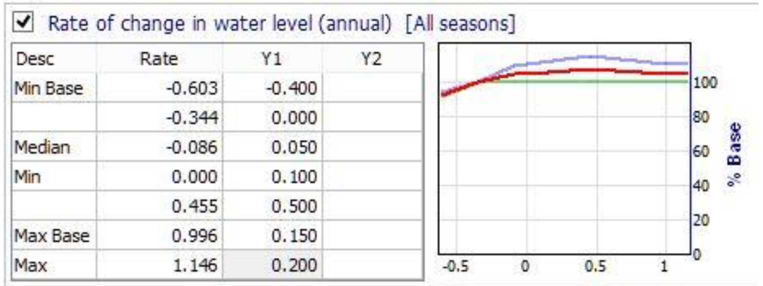
<table>
<tr><td colspan="2">Cattle Watering – Western Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Volume [All seasons, Site=WL]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.350</td><td></td></tr>
<tr><td>Min Base</td><td>582.603</td><td>-0.250</td><td></td></tr>
<tr><td></td><td>659.167</td><td>-0.150</td><td></td></tr>
<tr><td>Median</td><td>735.731</td><td>0.000</td><td></td></tr>
<tr><td></td><td>783.938</td><td>0.350</td><td></td></tr>
<tr><td>Max Base</td><td>832.145</td><td>0.650</td><td></td></tr>
<tr><td>Max</td><td>956.966</td><td>0.850</td><td></td></tr>
</table>
</td><td>Cattle watering and grazing along the shores of the Western Basin is prevalent. Changes in the volume of water in the lake affect the number of cattle that can be sustained in the Western Basin. Competition with agriculture is affecting the herds. Decreases in lake volume may reduce the extent of cattle watering and grazing..</td><td>High</td></tr>
</table>

<table>
<tr><td colspan="2">Cattle Watering – Western Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Rate of change in water level (annual) [All seasons]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-0.250</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.250</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>-0.200</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>0.850</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>1.000</td><td></td></tr>
</table>
</td><td>Rate of change in the water level impacts on the cattle herds that can access to the watering areas.</td><td>Moderate</td></tr>
</table>

9.5.7.2 Northern Arm

<table>
<tr><td colspan="2">Cattle Watering – Northern Arm</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Volume [All seasons]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.350</td><td></td></tr>
<tr><td>Min Base</td><td>41.718</td><td>-0.250</td><td></td></tr>
<tr><td></td><td>49.998</td><td>-0.150</td><td></td></tr>
<tr><td>Median</td><td>58.279</td><td>0.000</td><td></td></tr>
<tr><td></td><td>63.866</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>69.453</td><td>0.650</td><td></td></tr>
<tr><td>Max</td><td>79.871</td><td>0.850</td><td></td></tr>
</table>
</td><td>Cattle watering and grazing occurs along the shores of the Northern Arm. Changes in the volume of water in the lake affect the number of cattle that can be sustained. Competition with agriculture is affecting the herds. Decreases in lake volume will reduce the number of herds.</td><td>High</td></tr>
<tr><td>
☑ Rate of change in water level (annual) [All seasons]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>-0.603</td><td>-0.750</td><td></td></tr>
<tr><td>Min Base</td><td>-0.344</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>-0.086</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>0.000</td><td>0.050</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>0.200</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>0.300</td><td></td></tr>
</table>
</td><td>Rate of change in the water level impacts on the cattle herds that can access to the watering areas.</td><td>Moderate</td></tr>
</table>

9.5.7.3 *Southern Basin*

<table>
<tr><td colspan="2">Cattle Watering – Southern Basin</td><td></td></tr>
<tr><td>Linked indicator response curve</td><td>Explanation</td><td>Confidence</td></tr>
<tr><td>
☑ Volume [All seasons]
<table>
<tr><th>Desc</th><th>Mm3</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.250</td><td></td></tr>
<tr><td>Min Base</td><td>15.822</td><td>-1.150</td><td></td></tr>
<tr><td></td><td>19.144</td><td>-0.850</td><td></td></tr>
<tr><td>Median</td><td>22.467</td><td>0.000</td><td></td></tr>
<tr><td></td><td>24.709</td><td>0.250</td><td></td></tr>
<tr><td>Max Base</td><td>26.952</td><td>0.350</td><td></td></tr>
<tr><td>Max</td><td>30.995</td><td>0.400</td><td></td></tr>
</table>
</td><td>Cattle watering and grazing occurs along the shores of the Southern Basin. Changes in the volume of water in the lake affect the number of cattle that can be sustained in. Competition with agriculture is affecting the herds. Decreases in lake volume will reduce the number of herds.</td><td>High</td></tr>
<tr><td>
☑ Rate of change in water level (annual) [All seasons]
<table>
<tr><th>Desc</th><th>Rate</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min Base</td><td>-0.603</td><td>-0.400</td><td></td></tr>
<tr><td></td><td>-0.344</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>-0.086</td><td>0.050</td><td></td></tr>
<tr><td>Min</td><td>0.000</td><td>0.100</td><td></td></tr>
<tr><td></td><td>0.455</td><td>0.500</td><td></td></tr>
<tr><td>Max Base</td><td>0.996</td><td>0.150</td><td></td></tr>
<tr><td>Max</td><td>1.146</td><td>0.200</td><td></td></tr>
</table>
</td><td>Rate of change in the water level impacts on the cattle herds that can access to the watering areas.</td><td>Moderate</td></tr>
</table>

9.6 Assumptions and limitations

The following assumptions were made in analysing the impact of changes in Lake Sibaya from a socio-economic perspective:

- The domestic water use from the lake is only viable up to a depth of 7 m below natural ground level. It was assumed that the capacity of the pumps will not be able to handle the pumping head to deliver water to the various communities dependent on Lake Sibaya. When the water levels drop below 7 m then the municipality will use boreholes more in conjunction with the lake.
- The abundance of the fish is dependent on the fish biomass. Therefore the changes in fish biomass have been used as a proxy to determine how this change will affect the abundance of fish for communities to fish for household consumption.
- The presence and abundance of the emergent macrophytes was used as the indicator of the abundance of reeds and sedges for harvesting by the communities.
- The presence and abundance of the submerged rooted vegetation was used as the indicator of the abundance of water lilies for harvesting by the communities.

9.7 References and Data Sources

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