SOCIO-ECOLOGICAL SYSTEM MANAGEMENT OF THE LOWER PHONGOLO RIVER AND FLOODPLAIN USING RELATIVE RISK METHODOLOGY

Report to the

WATER RESEARCH COMMISSION

by

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WRC Report No. 2185/1/16

ISBN 978-1-4312-0811-1

July 2016

Obtainable from

Water Research Commission

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EXECUTIVE SUMMARY

BACKGROUND

The construction of the Pongolapoort Dam in the Phongolo River started in 1960 with the purpose to supply irrigation water for the proposed sugarcane and cotton plantations in the adjacent floodplain, the Makhathini flats. The floodplain of approximately 10 000 ha increases in size to 13 000 ha at full inundation. The floodplain extends to the confluence of the Phongolo and Usutu Rivers in Ndumo Game Reserve (NGR) up to the border with Mozambique. Ndumo was proclaimed a game reserve in 1924 with the primary objective of strict protection of its biodiversity. Today, NGR is a RAMSAR site because of its unique wetlands. Surrounding the NGR is communal areas that are heavily dependent on resources from the floodplain. However, the environmental sustainability of the floodplain has been questioned over time. Following an earlier ecological study of the floodplain system it was suggested that the ecosystem infrastructure of the Phongolo floodplain are maintained through controlled flood releases that were introduced to simulate the flood regime prior to the construction of the dam wall. The controlled flood releases were required to mimic the annual inundation of the floodplain. Although there are proper protocols for water releases it seems to be ignored and therefore not in accord with ecological needs. The environmental flow requirements to maintain the physical and chemical structure, biodiversity, ecosystem processes and functions in the Lower Phongolo River and floodplain may therefore not be met.

RATIONALE

Since the construction of the Pongolapoort Dam, there have been no major ecological studies that have monitored the floodplain wetlands of the Phongolo River. Very little is therefore known about the current ecological state as well as functioning and structure of the floodplain as a whole. The health and diversity of the fish, amphibians, water-associated birds and invertebrate communities have not been assessed recently. Information of this nature is needed for setting Environmental Flow Requirements EFRs and targeted conservation measures. Scientists and water resource managers need relevant information on the Lower Phongolo River and floodplain for the application and revision of protocols for water releases from the Pongolapoort Dam. This project was established with the objectives and aims as listed below.

OBJECTIVES AND AIMS

Aim 1

Conduct an integrated regional scale risk assessment of the Lower Phongolo River and floodplain using the Relative Risk Model (RRM) to establish and evaluate threats to the ecosystem.

Aim 2

Carry out an ecological integrity state assessment of the Lower Phongolo River and floodplain using the EcoClassification Level 3 methodology.

Aim 3

Use health and community structures of fish as indicators of ecological health, to assess the impacts of major stressors on the structure and function of the Lower Phongolo River and floodplain.

Aim 4

Determine and evaluate the bioaccumulation and biomagnification of DDT and other relevant organic pollutants and potential impacts thereof in the Lower Phongolo River and floodplain and the associated risk thereof to the local communities.

Aim 5

Provide all relevant data and information necessary to conservation authorities for the establishment of conservation plans for selected aquatic invertebrate and vertebrate species (macroinvertebrates, fish, amphibians and birds) of the Phongolo River and floodplain.

Aim 6

Evaluate the socio-economic implications associated with the use of fish as an ecosystem service (i); and (ii) evaluate the socio-ecological and cultural implications associated with the use of fish as an ecosystem service.

METHODOLOGY

Thirteen sampling sites, in two Ecoregions, were selected in the study area. Three sites were in the Lebombo Uplands Ecoregion with a site immediately below the dam wall and two sites in the Ngwavuma River. Ten sites were selected in the Lowveld Ecoregion with six sites associated with floodplain pans in the Lowveld Ecoregion. Of these six four were in the Ndumo game Reserve and in the communal areas. Two of the river sites were in the Phongolo River and one was selected in the Usutu River and used as a reference site. The

sites were carefully selected to include habitats where relevant information could be gathered to meet all the aims set for the study.

In situ physicochemical water quality variables were measured at each sampling site using an YSI 9260 water quality meter. Historic data collected for 11 water quality variables at 11 DWS monitoring sites in the vicinity of the Pongolapoort Dam were used to assess the water quality. The water quality data comprising monthly records from 1976-2012 were obtained from the DWS database. Comparing the upstream historical water quality data with the downstream monitoring points assessed the impact of the dam and related agricultural activities. The available data for each parameter were averaged to annual records and then analysed statistically to determine water quality trends per site from 1976 to 2012. The physicochemical driver assessment index (PAI), which forms part of the ecoclassification determination process, was applied to assess the present ecological state (PES) of the water quality within the study area.

The ecological integrity state assessment of the study area was done by applying the geomorphological driver assessment index (GAI) field forms to capture the data for habitat assessment. The observed impacts in the area were recorded and in addition with Google Earth images used to determine impacts in the various catchments. Sites and impacts were photographed and this information was used to monitor future changes to the sites and for comparison to historical photographs where available. Values obtained for the *in situ* physicochemical water quality parameters were also applied in the habitat assessment in the study area. At each site the riparian vegetation was assessed and the vegetation response assessment index (VEGRAI) scores were calculated at a Level III assessment level.

Macroinvertebrate sampling followed the standard SASS5 protocol. Changes in the macroinvertebrate community structure during high- and low-flow periods were analysed using cluster and NMDS ordination techniques in PRIMER (PRIMER Statistical Package). The SASS5 data were used to calculate the macroinvertebrate response assessment index (MIRAI) scores.

Five surveys were undertaken from November 2012 to April 2014 to include two low-flow or dry-season and two high-flow or wet-season surveys. The available fish habitat was classified based on the velocity and depth parameters and in each habitat type, or velocity-depth class, the extent of the potential cover for the fish, namely substrate, overhanging vegetation and undercut banks, was estimated and scored. A wide variety of standard fish sampling techniques were used to sample the different habitats, ranging from still-standing

water to fast-flowing rivers. The health of fish in this study was determined by using a macroscopic health assessment (fish health assessment index, FHAI) as well as a microscopic health assessment (histology-based assessment). Otoliths were collected from *Hydrocynus. vittatus*, *Oreochromis mossambicus* and *Coptodon rendalli* during all the surveys for age determination. The fish collected during the September 2013 survey were used for the macroscopic health assessment (FHAI) and the microscopic health assessment (histology-based). The fish collected during the April 2014 survey were used to determine the gonadal development stages to establish sexual maturity.

In phase one of the socio-ecological component of this study the point of departure was mostly explorative with the aim to, through constructive interviewing, observe, listen and record a selection of local leaders in the Jozini municipal area's view on the beneficiality of the Phongolo floodplain. Ten explorative questions were developed for the interviews with local community members. A mixed-methods sequential explanatory design procedure was adopted as basis for the second part of the human wellbeing section of this study. During this process, an initial quantitative phase of data collection and analysis was followed by a second phase during which qualitative data were collected and analysed. A sequential, exploratory, mixed-methods design was adopted as basis for the third and final part of the human wellbeing section of this study. It consisted of three phases: (1) a qualitative phase to explore people's interactions with natural resources, particularly fish; (2) the development of a second questionnaire on the basis of the qualitative findings in the broader Jozini municipal area as well as in the Ndumo community; and (3) a quantitative phase to verify and quantify the results (especially related to community's association or interaction with fish) as will be discussed in this section. This design is commonly used in cases where contextual sensitivity is required and where limited empirical knowledge exists.

The spatial scope of the RRM selected was the Phongolo River and its associated floodplain pans from below the Pongolapoort Dam, down to the Mozambique border. It extends for approximately 50 km in length with an adjacent floodplain pan system of 130 km^2. Risk regions were defined based on the degree of interaction of human communities with the river and associated floodplain pans. Risk Region 1 (RR1) extends from the Pongolapoort Dam to the northern edge of the Othobothini ward boundary (north-west bank of the Phongolo River) on the Phongolo River (-27.386289-S, 32.142684-E), Risk Region 2 (RR2) was from the boundary of RR1 and includes the Nondabuya, Mboza, Bhenindoda, Kwazamazama, Madonela Shemula, Shemula Gata, Lukwane, Kwa-Ndaba, Makhane, Ndumu and Kwamzimna wards up to the boundary of the Ndumo Game Reserve (-26.929993-S; 32.324131-E). Risk Region 3 (RR3) includes the Phongolo River and associated pans within

the Ndumo Reserve. Two general management endpoints were identified, i.e. endpoints related to maintenance of biodiversity and utilisation of fish as a natural resource. Four different conceptual models were developed related to maintenance of fish, amphibian and bird biodiversity and utilisation of fish as a protein source. These conceptual models were formatted into Bayesian network (BN) structures and the models were parameterised. The BN models and the preliminary analyses, the model's structure, parameterisation and findings were evaluated. The process was completed by conducting a sensitivity analysis of the model and revising the data with new evidence or knowledge.

RESULTS AND DISCUSSION

The Bayesian Belief Network – Relative Risk Model (BN-RRM) used to determine the ecological risk of anthropogenic and flow-related impacts showed that the ecosystem services provided by the Phongolo floodplain have undergone significant changes. Risk Regions 1 and 2 indicated a small likelihood for a moderate risk state for maintenance of frog biodiversity and it may necessitate further monitoring. However, the greater than 50% likelihood of moderate risk found to the endpoints will require management interventions and monitoring. The observed moderate risk posed to the biodiversity and subsistence fisheries in Risk Regions 1 and 2, and the more than 50% likelihood that there would be low risk to these endpoints in Risk Region 3, suggests that the Ndumo Game Reserve is important in providing adequate protection to the upstream regions of the Phongolo floodplain. Although the probability of endpoints being in a high risk (unacceptable state) state is low, ongoing monitoring and regulation should be considered.

The Physicochemical driver Assessment Index (PAI) model indicated that the water quality is generally in category C due to impacts upstream of the study area. The analyses of historical data for the area upstream of the Pongolapoort Dam showed that the water quality is in a poor state. Upstream from the impoundment elevated levels of nutrients as well as salinity were recorded and these elevated nutrient levels can result in eutrophication of the water resources if not managed. The downstream of the impoundment poor water quality was observed with a decreasing trend in nutrients (PO_4 and NH_4) over the past decades, while there has been an increase in salinisation (as measured in EC and K). Low DO concentrations were found except for the Usutu River. If the contamination of current upstream agricultural activities continues eutrophication might become a problem in Pongolapoort Dam in the future.

The macroinvertebrate community showed a clear separation between high- and low-flow (wet and dry respectively) sampling seasons at most sites in the system, most notably in the

lower Ngwavuma, Phongolo and in the Usutu Rivers. The diversity in reference samples showed relatively similar species compositions under high- and low-flow conditions, indicating that there was little change in the reference community between high- and low-flow seasons. The flows released from the dam into the Lower Phongolo River result in macroinvertebrate communities that are quite similar to the reference community during high and low flows. Despite an observed relative similarity between the reference community and the majority of macroinvertebrate samples collected during the study, the MIRAI EC for all sites ranged between C-D, which is cause for concern.

The removal of natural vegetation by land clearing for cultivation and housing, increased grazing pressure, trampling, removal of wood for fuel and building material and exposure of soil result in erosion. This is particularly evident in the riparian zones where erosion is a problem and bank stability is compromised. Sand-mining is also a matter of concern, as the river banks and alluvial deposits in the active channel of the Phongolo River are mined.

The modified suitable habitat in the rivers in the lowland reaches lowers the scores for the fish and macroinvertebrate diversities and this may have a negative impact on the EcoStatus categories. The FRAI scores calculated for the sites with a C as the highest Ecological Category at the reference site showed that the instream habitats were more severely impacted than the riparian vegetation. The VEGRAI scores confirmed this observation. The sites on the Phongolo River closest to the high-flow releases were “seriously modified with an associated loss of natural habitat, biota and basic ecosystem functions that is extensive” and in an E ecological category. A downstream improvement was observed in the Phongolo River. The Ngwavuma River was classified as being in a D Ecological Category, based on the downstream deterioration found in the instream habitat caused by the negative anthropogenic impacts on the river.

From the findings, it is evident that *O. mossambicus* (Mozambique tilapia) and *C. rendalli* (Red breasted tilapia) do use Nyamithi Pan as a refuge area to breed in. The community structures of these species in the pan indicated that it is largely populated by cichlids between the ages of four to 10 years old. Very few young cichlids were found in the Nyamithi Pan and could be a cause of concern due to the pressure specifically on the adult *O. mossambicus* (e.g. crocodiles, tigerfish and parasites). The majority of *H. vittatus* (Tigerfish) was small and this can be attributed to the fact that this species is increasingly difficult to sample as they grow bigger. More sampling is needed to understand the biology and ecology of this species from Nyamithi Pan.

Lindane, chlordane and DDT were the organic compounds that bioaccumulated at high levels in the fish tissue. The combined effect of environmental conditions and the impacts related to pesticide presence are currently affecting the health of the fish species used for the assessment of biomarker responses. DDT had the highest accumulation levels in all species at all the sampling sites. The toxicant levels tended to be elevated over the highest flow periods, mainly in the Phongolo River. The elevated toxicant levels tended to persist in Nyamithi Pan during low-flow periods as a result of high evaporation rates and the lack of freshwater inflows. The flood release events affected CEA levels as more energy was expended to compensate for increased water pressures. The fish species studied displayed individual and specific reactions in the biomarker responses. These changes in the toxicant levels during wet and dry seasons vary, and the water volume and pesticide application are probably causing these fluctuations. The fish species have regulatory mechanisms to cope with the varying levels of contamination that prevent a permanent or long-term effect on the physiological functioning of the organisms. The health status of the fish studied is therefore not affected. The current fish populations in the area will remain stable and no changes in diversity are expected. Future monitoring of the biomarker responses is advised to be able to identify changes in the biomarker responses and OCP levels in the surface water of the system. No cytotoxic responses were observed in any of the extracts examined in cell viability assays. This finding corroborates the findings on biomarker responses.

Wetland habitat degradation and loss, invasive competitors and pollution are factors that have the potential to negatively affect the Lower Phongolo River and wetland system. Especially for localities outside protected areas, the wetlands in the Lower Phongolo River floodplain are generally heavily exploited for water abstraction, domestic use, and agricultural activities. The invasive freshwater crayfish species *Cherax quadricarinatus* that is already present in the Phongolo system has the potential for a large impact on southern African freshwater ecosystems in general, including negatively affecting freshwater crab populations. Changes to natural flood regime of floodplains pose a threat to the fish biodiversity. For the past 10 years floods were released during spring (September and October), which differs from the natural high-flow season that occurs mainly during the summer months (November to January). Several species that are dependent on high flow during the summer months in order to breed are now left with very little, if any, habitat and often seek refuge in pans that eventually dry up. The sampling of only 37 of the 43 known species from this area is probably an indication of the effect of habitat loss. *Labeobarbus marequensis*, is one the six species not sampled and seems to be locally extinct as it was last collected before the severe drought of 1983. The introduction of the alien redclaw crayfish (*C. quadricarinatus*) might pose a serious risk to tadpoles. Studies to document the

threat that redclaw crayfish might pose should be a high priority as it is of national importance. Furthermore, the small seasonal well-vegetated pans are the prime breeding sites for a number of anuran species with very specific habitat requirements and the diverse habitats in the Ndumo Game Reserve cater for the conservation of a variety of species. This study showed that spatial differences and temporal changes play a significant part in the bird biodiversity of Ndumu Game Reserve and by extension thereof, also the rest of the Phongolo floodplain. The message is clear: small-scale habitat heterogeneity needs to be preserved, although a measure of disturbance might be tolerated. In addition, highly conserved areas should form part of the mosaic of the Phongolo River and floodplain.

In relation to participants' views regarding the Lower Phongolo River and Floodplain, and the controlled release of water from the Pongolapoort dam, most residents agreed that it played an important role in their lives. Amongst other it supported agricultural activities, subsistence fishing and small scale commercial ventures. Furthermore it enabled them to water their livestock, engage in religious rituals such as baptism, and provide water for household use. However, participants expressed concerns about the management of controlled water release onto the floodplain and a main concern was that the ensuing flooding often washed away vegetable gardens. In some cases, losses of livestock were reported due to drowning following water release. Some community leaders (inclusive of *Indunas*) and residents were concerned that the flooding blocked access roads to schools. Results from the second phase of the social study showed that the community currently does not pose any threat to the fish reserves in the Floodplain. Though fish is readily consumed, it does not necessarily come from the Ndumo pans and rivers in the area, but from fishing practices further west at the Pongolapoort Dam. Cultural fishing practices, as generally expected from an indigenous knowledge system perspective, appear to be lower than had been anticipated. This further means that cultural fishing practices pose no immediate threat to the fish communities in the Ndumo area. Thus, with regard to the conservation implications for the area, it can be said that given the sensitivity of the floodplain ecosystem additional research on fish reserves further west and closer to the Pongolapoort Dam. The continuous monitoring of the situation, are important to assess and ensure the sustainability of human-fish interactions in the region. The findings of socio-ecological section of the study further revealed that, despite significant challenges such as poverty, poor infrastructure, concerns about education, and an inadequately perceived provision of basic municipal services, members of the Ndumo community exceeded above average levels of psycho-social wellbeing generally. The rural nature of the community, which allows for agricultural practices, probably is the main reason for this status. In addition, there is a tendency to maintain and respect traditional moral values which allows people to feel secure and safe. Other attributes that contribute to the

wellbeing of the Ndumo community are their homogeneous cultural identity and their mainly Christian religious orientation. The findings of this study also raise the issue of the impact of communities being primarily governed by traditional, rather than local government authority.

CONCLUSIONS

In this study we demonstrated that the BN approach can effectively be used as a tool for resource and conservation managers. We were able to further demonstrate that the resource protection afforded to the NGR provides a biodiversity refuge in the Phongolo catchment. Through different scenarios, i.e. increased human disturbances in riparian zones as well as increased fisheries, it was established that the socio-ecological risk distribution in NGR would reach similar high risk conditions to those outside of the Reserve. Risks posed by changes in both water quantity (in this example a singular parameter change in flood releases) and quality (in this example we used DDT bioaccumulation in aquatic biota) were addressed using the BN model. The graphic nature of the interface and outputs coupled to the ability of the BN models to generate and evaluate alternative scenarios makes it a useful tool for resource management. The form of the risk distribution curves serves as a sensitivity analysis of the BN model outputs. It therefore provides an indication of where additional information will be required to reduce uncertainty. The generation of information to reduce the uncertainty in the risk predictions will in essence drive the structuring of future monitoring programmes, i.e. the monitoring becomes hypothesis driven. The new information generated by the monitoring can be used to update the input node descriptions and if necessary the rank scores making the BN model ideal for adaptive management application. The application of BN-RRM models can contribute to greater application of adaptive management practices in resource and conservation management in the Phongolo River catchment. The application value within an adaptive management framework is due to the BN-RRM model communicating uncertainty in a quantifiable manner, the interactions of disparate ecological values are visually observed through the graphical interface, and once the model has been developed it can easily be updated and refined by resource managers trained in this model, thereby increasing ownership in the adaptive management process.

RECOMMENDATIONS FOR FUTURE RESEARCH

- The Relative Risk Methodology that was developed during this project provides an innovative way to contribute to the determination of water resource protection measures and associated objectives as required by the National Water Act (Act 108 of 1998) of South Africa and should be considered by Ezemvelo KZN Wildlife, DEA and DWS as an option. These measures include the Reserve Determination procedures, Water Resource Classification procedures and the Resource Quality Objectives. The outcomes of the risk assessment and the associated evidence (water resource use and protection information, and the proposed and evaluated river quantity, quality, habitat and biota objectives) provide essential information that could be incorporated into the Resource Quality Objectives determination procedures for Water Management Area 6 (including the Phongolo River). Future monitoring can then be incorporated into the RRM model to increase predictive power.
- The model developed in this study should be rolled out to the various stakeholders, including amongst others Ezemvelo KZN Wildlife, DEA and DWS, through workshops focussing on the training of the resource managers in the use and implementation of this model.
- For the purposes of developing the BN-RRM model we only focused on four endpoints covered in this study. In some instances the metrics used to provide causal links between stressors and effects were fairly course, e.g. for the maintenance of fish biodiversity the measure of flooding was only related to habitat availability. Other measures such as role of floods in maintaining ecosystem processes in the floodplain pans will increase the certainty associated with the risk predictions.
- It therefore remains essential that fundamental research be conducted and supported financially in order to provide the necessary data that address these processes.
- One of the outcomes of this project was the first report of the invasive freshwater crayfish, *C. quadricarinatus*, from this region as well as the first report in Africa of its associated parasites. The impacts of this alien and its parasites on indigenous aquatic fauna must be investigated and its current Alien and Invasive Species listing of 1b should be re-assessed.
- High levels of DDT were detected in all the fish species tested and thus pose a potential serious health risk to the local community. The RRM further showed that an increase in current DDT levels will increase human health risks. Based on these finding it is imperative that the continued use of DDT in this area should be re-assessed as well as the current health status of the people of this region should be investigated.

ACKNOWLEDGEMENTS

- The Water Research Commission is sincerely thanked for funding this project.
- Adri Joubert, Unit for Environmental Sciences and Management, North-West University (Potchefstroom Campus), Potchefstroom is hereby thanked for all her hard work as logistic and financial assistant on this project. Every successful field excursion was due to Adri's planning and organisational skills.
- Dr Richard Greenfield (UJ), Petri Bronkhorst (NWU) and Godfrey Magodla are sincerely thanked for their logistical and technical support during the field excursions.
- We also would like to thank Ingrid Buchan for proofreading and editorial comments on the final report.
- Esemvelo KZN Wildlife, especially Catherine Hanekom and the late Robert Karssing, who initiated this project, are sincerely thanked for their support of this project and research permits to work in the Phongolo and Ndumo Game Reserve.

The following students completed all or part of their research for post graduate degrees at the different collaborating universities as part of this project, and are hereby thanked for their considerable contributions to the research and this final report:

Botha, Vidette – MSc (North West University)
Chavalala, Lincon – MSc (University of Venda)
Coetzer, Annerie – BSc Hons & MSc (North West University)
Delport, Michelle – BSc Hons (North West University)
De Swardt, Jurgen – MSc (North West University)
Edwards, Claire – MSc (University of Johannesburg)
Hannam, Melissa – BSc Hons (North West University)
Khosa, Dumisani – MSc (University of Venda)
Kopeshe, Zezetu – MSc (University of Zululand)
Landsberg, Riette – BSc Hons (North West University)
Mkhonto, Mary – MSc (University of Johannesburg)
Mpete, Tinyiko – MSc (University of Johannesburg)
Netherlands, Edward – BSc Hons & MSc (North West University)
Pretorius, Abigail – BSc Hons (North West University)
Prinsloo, Simone – BSc Hons & MSc (North West University)
Wolmarans, Nicolaas – BSc Hons & MSc (North West University)

The authors would also like to thank the following Reference Group Members of WRC Project No. K5/2185 for their assistance and constructive contributions to the project:

Mr BR Madikizela	Chairperson (Water Research Commission)
Dr IR Bills	South African Institute for Aquatic Biodiversity
Prof CM Breen	Charles Breen & Associates
Dr CWS Dickens	Institute of Natural Resources
Prof CT Downs	University of KwaZulu-Natal
Mr DG Hay	Hay & Associates / University of KwaZulu-Natal
Mr F Madizwa	Conservation International
Dr SA Mitchell	Bufo Technologies / PR Consulting
Mr C Mulqueeny	Esemvelo KZN Wildlife
Dr M Ndou	Nulandis
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Mr M Salagae	Department of Water Affairs
Dr RH Taylor	Consultant
Ms C Todd	Independent Freshwater Ecologist

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LIST OF ABBREVIATIONS

AChE	acetylcholinesterase
APE	absolute percentage error
CF	condition factor
DEA	Department of Environmental Affairs
DDT	dichlorodiphenyltrichloroethane
EC	ecological category
ECon	electrical conductivity
EFR	environmental flow requirements
EIS	ecological importance and sensitivity
FROC	frequency of occurrence
FHAI	fish health assessment index
FRAI	fish response assessment index
GAI	geomorphological driver assessment index
GSI	gonadosomatic index
HSI	hepatosomatic index
IHAS	Integrated Habitat Assessment System
IWRM	integrated water resource assessment
KZN	KwaZulu-Natal
MOL	minimum operating level
MIRAI	macroinvertebrate response assessment index
NGR	Ndumo Game Reserve
NMDS	non-metric multidimensional scaling
OCPs	organochlorine pesticides
PAI	physicochemical driver assessment index
PES	present ecological state
REC	recommended ecological category
RS	reference state
RRS	Relative Risk Model
RSQs	resource quality objectives
SL	standard length
SSI	splenosomatic index
TOPS	threatened or protected species
TL	total length
VEGRAI	vegetation response assessment index

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1 INTRODUCTION AND AIMS OF THE PHONGOLO RIVER AND FLOODPLAIN PROJECT

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1.1 Introduction

The construction of the Pongolapoort Dam in the Phongolo River started in 1960 with the proposed purpose to supply irrigation water for the sugarcane and cotton plantations in the adjacent floodplains known as the Makhathini flats (Van Vuuren, 2009). It is located at the eastern end of a narrow gorge between the Lebombo and Ubombo mountain ranges in the Maputaland area of northern KwaZulu-Natal (KZN) in South Africa (SA) (Heeg & Breen, 1994). Below the dam is a floodplain of approximately 10 000 ha (Breen et al., 1978), which increases in size to 13 000 ha at full inundation (Heeg & Breen, 1982; Rossouw, 1985). The floodplain extends to the confluence of the Phongolo and Usutu Rivers in Ndumo Game Reserve (NGR) up to the border with Mozambique (Figure 1.1). Ndumo was proclaimed a game reserve in 1924 with the primary objective of strict protection of its biodiversity. Today, NGR is a RAMSAR site because of its unique wetlands. Surrounding NGR is the communal area that is heavily dependent on resources from the floodplain. However, the environmental sustainability of the floodplain has been questioned over time.

The concept of maintaining ecosystem services in the Phongolo floodplain through water management programmes was first initiated as a result of the research work done by Coke (1970a, b) and **Phélines** et al. (1973) on the adverse effects of the dam on fish spawning. The concept was further emphasized nine years after commissioning of the dam (1973) (Heeg & Breen, 1982). Once the detailed ecological study of the floodplain system had been completed, it was recommended that controlled flood releases be made to simulate the flood regime before the dam was built so as to maintain the floodplain as far as possible in a natural state (Coke, 1970a; Heeg et al., 1980; Heeg & Breen, 1982).

Therefore, the operating rules based on the minimum level of operation without any damage to the reservoir ecosystem (minimum operating level (MOL) were agreed on for controlled water releases

from the dam (Alexander, 1982). The controlled flood release required to mimic the river's natural flood pattern for annual inundation of the floodplain was set at 2 m^3/s for winter (May to July) base-flow, 80 m^3/s during early summer (August to November) and 600-800 m^3/s for late summer (December to April), so as to maintain the inter-relationship between flooding and the biology of the system (e.g. fish migration). These recommendations have been largely ignored, because the MOL of Pongolapoort Dam was rarely reached due to the persistence of dry years, resulting in low flows in the river (Rossouw, 1985). Therefore, 40 years after the commissioning of the dam, proper management schemes to control flood releases and their effects on the downstream floodplain ecosystem remain unresolved. The Phongolo floodplain is now mainly separated from the river channel and is only flooded after controlled and less varied releases from the dam (Jaganyi et al., 2008; Lankford et al., 2010).

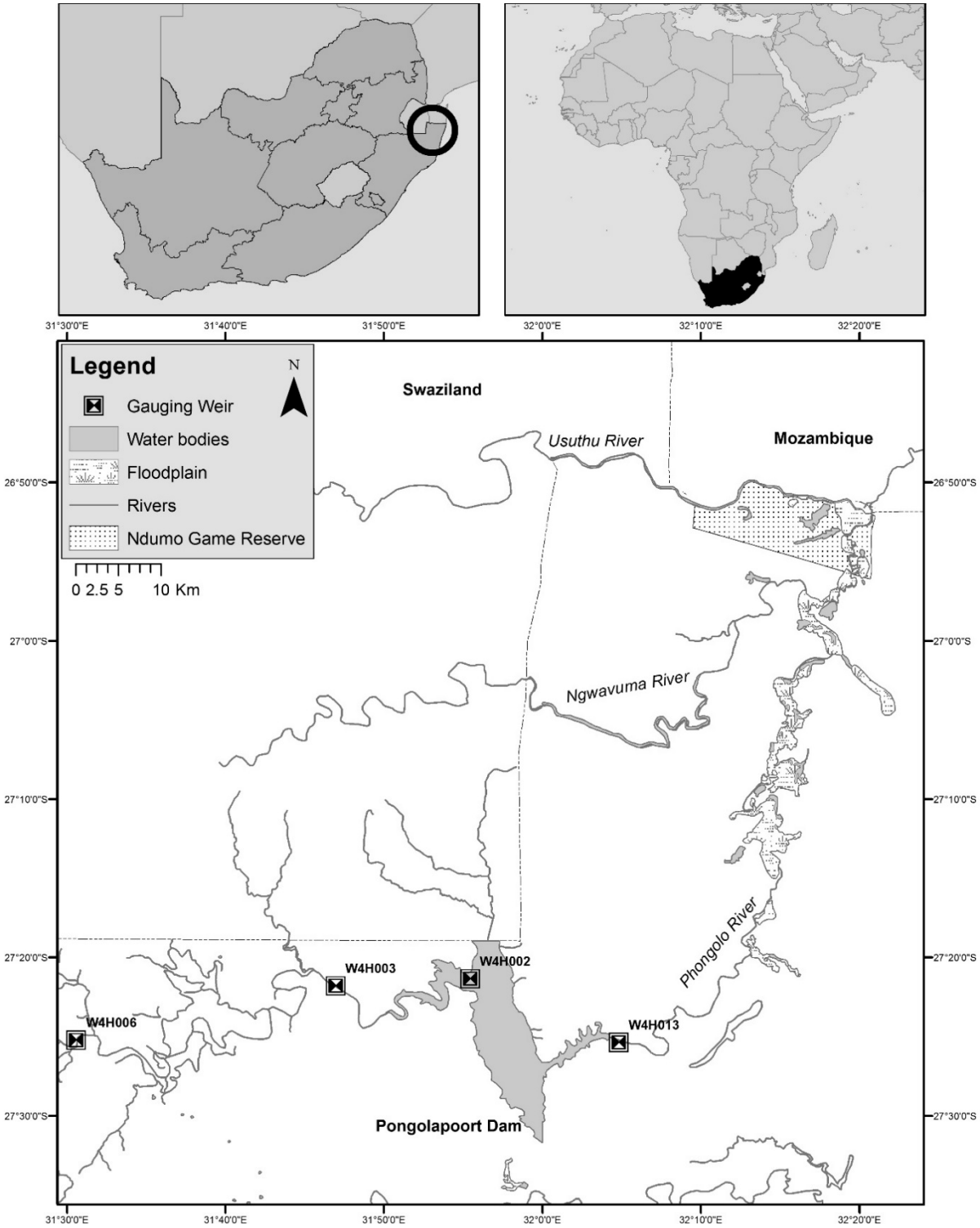


Figure 1.1. Map of the Pongolapoort Dam, the Lower Phongolo River and its associated floodplain in north-eastern South Africa.

The principle of environmental flow requirements (EFR) refers to the water provision requirements of aquatic ecosystems to maintain their physical and chemical structure, biodiversity, ecosystem processes and functions that give them their specific character (Acreman, 2001; Bunn & Arthington, 2002; Dyson et al., 2003; Arthington et al., 2006). The EFR is now regarded as a key element of integrated water resource management (Dyson et al., 2003) as the environmental water reserve (ecological Reserve) will also indirectly support people by maintaining valuable ecosystem services (Acreman, 1998). As environmental flow requirements to maintain ecosystem services (e.g. biodiversity) of the Phongolo floodplain were not established at the time of dam construction, the ecological integrity of the floodplain and associated wetlands within and outside the protected NGR is threatened by the modified flow regimes (volumes, rate, duration and timing of flows) at the Pongolapoort Dam wall (Heeg & Breen, 1982). In addition, the river and linked aquatic ecosystems are also threatened by agricultural development in the region. It is important to note that South Africa is one of the few countries in Africa legally supporting EFR (The Constitution – Act 108 of 1996; Water Act 36 of 1998; and National Environmental Management Act 107 of 1998) that give priority of water to river ecosystems once basic human needs are met (Rowlston & Palmer, 2002). Despite these progressive policies, the practicality of EFR remains a challenge as it is difficult to quantify the volume of water required to maintain ecological processes.

The purpose of this introduction is to give an overview of the ecological and socio-economic importance of the Phongolo River, its floodplain and to highlight the hydrological and ecological research conducted since dam construction. The introduction will also suggest possible future research needed to gain an understanding of the structure, functioning and requirements of the floodplain for maintenance of ecosystem services. The information will also serve as a base for the management of the floodplain through flood releases that match environmental flow requirements.

1.2 Hydrology of Phongolo River and its associated floodplain

The Phongolo River flow has been gauged since before the construction of the Pongolapoort Dam, from 1929-1976 at Golela (W4H002), from 1968-2013 at Bokfontein (W4H006) and from 1950-1995 at Mhlati (W4H003). The gauging station at Jozini (W4H013) was installed in 1983 after construction of the dam (Figure 1.1).

Heeg and Breen (1982) used daily flows of the 47-year period (1929-1976) at gauging station WH4002 upstream of the dam, to estimate the median river flow as 1 025 x 10^6 m^3/a with a range (690 x 10^6 m^3/a to 1 360 x 10^6 m^3/a) in 50% of the years. The monthly records for this period indicate that river flow is strongly seasonal. The major portion of the flow (70% of total) occurs during the period November to March, with greatest discharge (17.5%) in February. The lowest flow

is expected from June to September accounting for almost 10% of the flow. As expected, the flow at the other two upstream gauging stations (W4H003 and W4H006) is seasonal (Figure 1.2). The annual flow downstream of the dam wall at Jozini (W4H013) has been reported as 630 x 10^6 m^3 (Hughes, 2000), 645 x 10^6 m^3 (DWAF, 2004) and 785 x 10^6 m^3 (Jaganyi et al., 2008). The construction of Pongolapoort Dam has altered the seasonal flow to more uniform flows throughout the year as depicted by median flow data at the Jozini gauging station (W4H013, 1983-2013) installed after construction of the dam (Figure 1.2). The mean monthly discharge at the height of the peak wet season (post-dam construction) at Jozini (W4H013) is lower (32.5778 x 10^6 m^3) than the historical flow at Golela (W4H002) (58.865 x 10^6 m^3) (1929-1976). This shift from seasonal to more uniform flow has an impact on the amount of water that can flow into the floodplain.

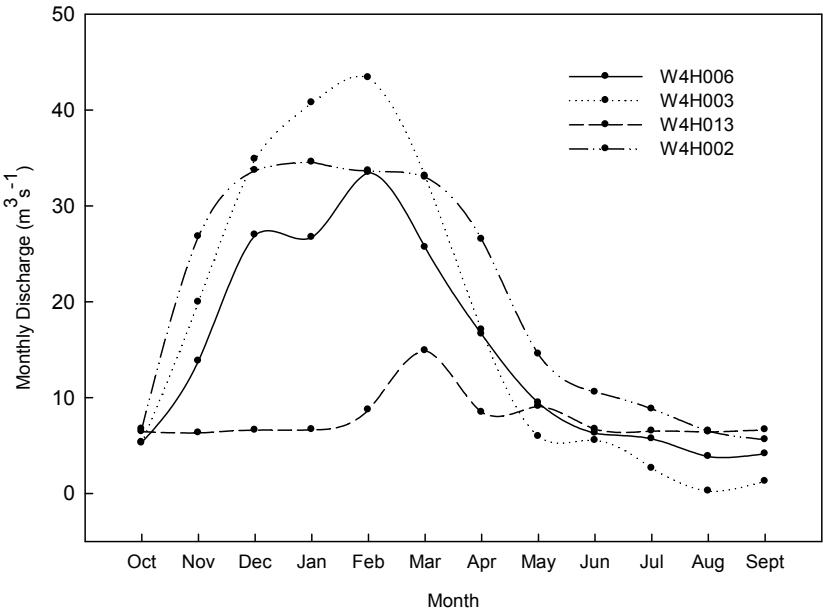


Figure 1.2. A hydrograph of the Phongolo River at three upstream gauging stations: Golela (W4H002, 1929-1976), Mhlati (W4H003, 1950-1995), Bokfontein (W4H006, 1968-2013), and one downstream gauging station Jozini (W4H013, 1983-2013) (source data: DWAF database).

However, other developments in the upstream area of the dam have contributed to low flow into Pongolapoort Dam. For example, Bivane Dam upstream of the Pongolapoort Dam was constructed in 1995 to supply irrigation water for sugar cane plantations at Impala irrigation scheme. The trend in water abstraction at Impala irrigation scheme has generally increased over time from 125 x 10^6 m^3 in 1996 to 211 x 10^6 m^3 in 2003. Downstream of Pongolapoort Dam is the Makhathini irrigation scheme, with abstractions increasing from 18 x 10^6 m^3 in 1996 to 60 x 10^6 m^3 in 2003 (Jaganyi et al., 2008).

1.3 Socio-economic importance of the floodplain

The proximity to water has always been an important factor that governs the distribution of rural communities. The human population that is directly or indirectly dependent on the Phongolo floodplain has grown over the past 30 years from 30 000 to over 150 000 (Breen et al., 1998; Lankford et al., 2010). A high concentration of the generally poor Tembe Thonga community now reside on the Makhathini flats near the floodplain where water is easily accessible to both humans and livestock (Heeg & Breen, 1982). The Ndumo district is part of the uMhlabuyalingana and Jozini Local Municipalities where 87% of the households live in poverty (Statistics South Africa, 2001). The high poverty levels are indicated by a high dependency on government subsidy for some of the basic needs (Lankford et al., 2010). Ecosystem goods from the floodplain (e.g. fish, fruits, reeds, thatch grass, firewood) are, therefore, important to the socio-economic development of these communities. The increase in the number of people indirectly benefiting from the floodplain resources is, however, a threat to sustainable utilisation of the floodplain resources. This is evidenced by the fact that there has been a 40% increase in the transformation of nearby floodplain natural vegetation into agricultural land between 1955 and 2003 (Lankford et al., 2010). The need to maximize gain from subsistence agriculture in the floodplain has also seen the introduction of fertilizers and banned chemicals like dichlorodiphenyltrichloroethane (DDT) (Sereda & Meinhardt, 2003; 2005). The use of these chemicals is not only a threat to aquatic biodiversity, but also to the quality of water and fish consumed by the people living along the Phongolo River and floodplain pans.

The floodplain is also of cultural significance to the local community (Heeg & Breen, 1982; Merron et al., 1994a). The traditional fishing methods practised during flooding, namely isifonya and mona basket, were of importance to instil ubuntu (togetherness and responsibility) and ukuhlaba (control over the use of open access resources) (Heeg & Breen, 1982; Lankford et al., 2010). These traditions are now being eroded due to the altered flow regimes and by an influx of new people who may not have the same culture and affiliations, hence the sustainable utilisation of an open access resource is under threat.

The culture associated with fishing in Phongolo floodplain has allowed floodplain communities to regard fish as a freely accessible resource. The fishes of the Phongolo floodplain form a crucial component of their diet providing a cheaper source of protein than chicken or beef. Approximately 98% of the local people consume fish (Kok, 1980). Communities exploit the pans for fishing in preference to the river because each pan is unique in fish composition (Jaganyi et al., 2008). However, people living on the floodplain have over the years after construction of the dam reported drastic changes to the ecosystem services, especially a reduction in fish yields and a change in

fishing seasons (Heeg & Breen 1982; Jaganyi et al., 2008). The historical catches through traditional methods were timed to coincide with periods of pan flooding. This is in contrast with the current fishing season which begins in October after the flood release until February at the peak of the rainy season (Jaganyi et al., 2008). The Pongolapoort Dam reduces streamflow below the dam, thus during the summer flood peak the floodplain pans are quickly disconnected from the main river, resulting in a reduction in fish yields. During these periods of low flow, fish in the pans are generally overexploited. Merron et al. (1994a, b, c, d, e, f) reported a dominance of smaller fish of less than 75 mm in the highly exploited pans outside NGR, whereas catch per unit effort (CPUE) for large species (74−124 mm) was higher in the protected NGR.

A general decrease in yield of fish from the floodplain was observed over time. Kok (1980) estimated a yield of 500 t/a relying on the total flooded area of 10 350 ha (Breen et al., 1978). However, Heeg and Breen (1982) estimated a higher yield of 500-700 t/a relying on the maximum retention level of pans (2 700 ha), that is the area of the pans inundated after the flood has receded. James (1992) states that a more realistic yield would be between 150 and 250 t/a. A further decrease in yield of 39.3 t/a was noted by Weldrick (1996). The decrease in fish yield was attributed to irregular water releases, which are often asynchronous with biological rhythms of fish together with overfishing, primarily as a result of an increase in human population residing immediately around the floodplain (Heeg & Breen, 1994; Jaganyi et al., 2009).

1.4 Ecological importance of the floodplain

The Phongolo River forms South Africa's largest and most diverse floodplain system (Kok, 1980; Rossouw, 1985). It serves as a habitat to five terrestrial communities (*Acacia xanthophloea* – *Dyschoriste depressa*, *Ficus sycomorus* – *Rauvolfia caffra*, *Cynodon dactylon*, *Cyperus fastigiatus* – *Echinochloa pyramidalis*, Phragmites) and two aquatic plant communities (algae, aquatic hydrophytes). The distribution of these communities is governed by fluctuating water levels, soil type and disturbance (Heeg & Breen, 1982). The aquatic fauna in the Phongolo floodplain system include tropical fish species and several migrant bird species which use the floodplain as a temporary feeding or breeding habitat (Heeg & Breen, 1982; 1994; Whittington et al., 2013). The ecological value of the Phongolo floodplain was first evaluated with emphasis on the adverse effects of dam construction on fish spawning (Coke, 1970a, b; **Phélines** et al., 1973). Between 35 and 50 fish species (Heeg et al., 1980; Merron et al., 1994a) have been recorded on the floodplain, making it the most diverse fish fauna community in South Africa (Heeg & Breen, 1982). Half of these species have their southern limit of distribution in the Phongolo system (Kok, 1980). No other detailed information on the health of fish and ecology of the floodplain in the Phongolo system is

available. Such information is, however, vital for a sustainable fishery especially under the prevailing conditions of poverty and human population increase.

Approximately, 90 floodplain pans of various sizes and permanence have been recorded in the Phongolo floodplain system (Breen et al., 1978; Heeg & Breen, 1982). The total area of these floodplain pans is approximately 26 km^2 or 20% of the floodplain surface (Heeg & Breen, 1982; 1994). In the floodplain, hydrologically distinct wetland types can be distinguished. A first major split is between systems that hold water year-round, called permanent wetlands or permanent pans. A second type only holds water for a variable period and are called temporary wetlands or temporary pans. A further distinction can be made on the basis of the connectivity of pans with the river. One type of pan forms after flood waters recede. A second type of pans off the floodplain, is entirely dependent on rainfall and is not connected to the river (i.e. endorheic systems). Temporary endorheic pans are generally abundant in arid and semi-arid areas where they often are the most important lentic waters with relatively high biodiversity (Brendonck & Williams, 2000; Jones & Day, 2003). The need to cope with periodic drying in temporary pans imposes severe constraints on biota such that only those species able to deal with drying are successful in these habitats (Wiggins, 1980). Periodic drying prevents permanent colonisation by fish and predatory invertebrates that are highly susceptible to drying, which does not mean that these systems are enemy free (Brendonck, 2002; Waterkeyn et al., 2011). The predators such as fish are restricted to relatively deep permanent or temporary pans that are regularly connected to the river through flooding (Wellborn, 1996). The water discharges at Pongolapoort Dam have, however, been erratic and are not synchronous with the biological rhythms of floodplain species. A result is the change in fish community structure, for example, a decrease in numbers of flood-dependent spawners like the *Labeo rosae*, has been observed in the Phongolo floodplain (Merron et al., 1994d-f; James, 1992, Merron et al., 1993).

The pattern of filling and drying out (length, frequency, timing; called the hydroregime) structures the spatiotemporal heterogeneity of floodplain habitats (Ward & Stanford, 1995), leading to a characteristic and high biodiversity. When pans are mainly river-fed, they often become refugia for river biota (Coke & Pott, 1971; Arthington et al., 2006; Bunn et al., 2006), spawning, breeding and foraging areas for migratory fish and other vertebrates (Lowe-McConnell, 1985; Ward et al., 1999; Tockner & Stanford, 2002) and a source of nutrients to the river (Power et al., 1996). Flow regulation through dam construction, in general, may therefore reduce this connectivity and alter succession trajectories in floodplain rivers and associated wetlands.

The resulting modified flow due to dam construction is also usually accompanied by shifts in the thermal regime which can influence the spawning behaviour of fish and life-history processes of

invertebrates (Penaz & Jurajda, 1995). The hydrological connectivity between river and floodplain also facilitates exchange of allochthonous and autochthonous particulate organic matter, dissolved organic matter, detritus, nutrients and even aquatic plant propagules (Hein et al., 2003). The periodic flood pulse is therefore key to both maintaining a healthy river ecosystem and the productivity of the surrounding wetlands (Baranyi et al., 2002).

A paucity of information exists on the biodiversity of the temporary aquatic systems in the Phongolo floodplain. Studies on temporary pans elsewhere have shown that they often harbour unique, highly specialized, and endemic species with restricted geographical distribution (King et al., 1996; Blaustein & Schwartz, 2001; Brendonck et al., 2008; Nhiwatiwa et al., 2014). Due to their temporary nature, they were shown to be especially vulnerable to changes in their hydrology and the local climate. The long-term species composition of these temporary pans is closely linked to habitat properties such as river connectivity and their spatial location (Nhiwatiwa et al., 2011). Some of the flagship organisms found in fish-free temporary aquatic systems are large branchiopods which comprise tadpole shrimps (Notostraca), clam shrimps (Spinicaudata, Laevicaudata and Cyclestherida), fairy and brine shrimps (Anostraca) (Brendonck et al., 2008). These relatively large species are accompanied by the common smaller zooplankton groups like cladocerans, copepods and rotifers (Brendonck, 1996; Hamer & Martens, 1998; Brendonck & Williams, 2000; Nhiwatiwa et al., 2009). These permanent inhabitants have peculiar life-history characteristics that involve the production of resistant dormant eggs that allow populations to persist despite the harsh environment of temporary habitats (Brendonck & De Meester, 2003).

The decreased flows in the Phongolo floodplain due to the construction of the Pongolapoort Dam will not only have an impact on the number of river-connected wetlands, but will also greatly influence local pool characteristics (e.g. permanence) as also observed in other temporary aquatic systems (Eitam, 2004; Jocque et al., 2007). In addition, regional factors (e.g. connectivity) (Tockner & Stanford, 2002) that determine structure and dynamics of communities in a metacommunity framework will change with altered flood regimes. The discharges do not mimic natural flow regimes because they are determined by external factors, such as water availability and dam capacity. The change in the pattern of the hydro-regime away from what is appropriate to sustain the required sate, is therefore a threat to the structure and functioning of these pans.

1.5 Use of pesticides on the floodplain

The Lower Phongolo River floodplain is defined as an endemic intermediate to low-risk malaria area (McHugh et al., 2011; Wepener et al., 2011). Spraying in this area takes place for the purpose of vector control, starting in January and extending through to the end of March (Bouwman et al.,

1990). The pesticide used for the application of indoor residual spraying is technical grade dichlorodiphenyltrichloroethane (DDT). DDT was used as a stock remedy and was the preferred pesticide for many South African farmers until it was banned in 1974. This banning led to a large decline in its overall use as a general pesticide (Van Dyk et al., 1982). The use of DDT continued informally in the agricultural sector, but mainly as part of malaria control programmes, until it was completely banned by the Stockholm Convention on Persistent Organic Pollutants in 1996 (Wells & Leonard, 2006). Substituting pyrethroid pesticides for DDT to control the malaria vector led to an increase in deaths related to and caused by malaria. This increase has led to the reintroduction of DDT (unbanning of it for specific use) as the principal malaria vector control pesticide and this practice has been supported by the World Health Organization (WHO) since 2006 (Ansara-Ross et al., 2012).

Although DDT is the main focus of this study, other organochlorine pesticides (OCPs) are also used within this area and have been found in the analyzed samples. These OCPs include lindane, (γ-HCH) and its by-products (α-HCH, β-HCH), trans-chlordane and trans-nonachlor (chlordane) as well as hexachlorobenzene (HCB). Both lindane and chlordane were found in smaller quantities within whole fish in Hartbeespoort and Voëlvlei Dams (Greichus et al., 1977), but have not been reported in the Phongolo River system. Lindane and chlordane are insecticides which are used for the management of crops. Control of lice and scabies with lindane shampoo is still common, even after its ban in agricultural use (Engeler, 2009). Chlordane is used for disease control in citrus plantations (Quinn et al., 2001). HCB is another persistent organic pollutant which was banned by the Stockholm Convention on Persistent Organic Pollutants and was previously used as a fungicide. Application of this fungicide was mainly to seeds for planting, and levels have been found in human breast milk (Jensen & Slorach, 1991). Only limited data are available on levels of HCBs within the Phongolo River system. Monitoring programmes within developing countries do not accurately keep track of pesticides that are used, even if they are banned substances and this means that contamination may still occur due to their continued use (Ansara-Ross et al., 2012).

1.6 Project rational and aims

Since the construction of the Pongolapoort Dam, there have been no major ecological studies that have monitored the vulnerable floodplain wetlands that are dependent on the Phongolo River. Very little is therefore known about the current ecological state, structure and functioning of the floodplain as a whole, as well as the health and diversity of the fish, amphibians, water-associated birds and invertebrate communities. Such information is needed for setting EFRs and targeted conservation measures. This should narrow the “gap” (Loucks, 1998) or “paradigm lock” (UNESCO, 2005) that often exists between scientists and water managers. In the light of this need for up-to-date and

relevant information on the Lower Phongolo River and associated floodplains, the current project was established with the following aims (relevant chapters indicated in brackets).

Aim 1: Conduct an integrated regional scale risk assessment of the Lower Phongolo River and floodplain using the Relative Risk Model to establish and evaluate threats to the ecosystem (**Chapters 9 & 10**).

Aim 2: Carry out an ecological integrity state assessment of the Lower Phongolo River and floodplain using the EcoClassification Level 3 methodology (**Chapters 2, 3, 4 & 10)**.

Aim 3: Use health and community structures of fish as indicators of ecological health, to assess the impacts of major stressors on the structure and function of the Lower Phongolo River and floodplain (**Chapters 2, 5 & 10**).

Aim 4: Determine and evaluate the bioaccumulation and biomagnification of DDT and other relevant organic pollutants and potential impacts thereof in the Lower Phongolo River and floodplain and the associated risk thereof to the local communities (**Chapters 2, 6, 9 &10**).

Aim 5: Provide all relevant data and information necessary to conservation authorities for the establishment of conservation plans for selected major aquatic invertebrate and vertebrate species (macroinvertebrates, fish, amphibians and birds) of the Phongolo River and floodplain (**Chapters 7, 9 & 10**).

Aim 6: Evaluate the socio-economic implications associated with the use of fish as an ecosystem service (i); and (ii) evaluate the socio-ecological and cultural implications associated with the use of fish as an ecosystem service (**Chapters 8, 9 & 10**).

It is hoped that the findings of this study will provide the evidence base to inform the development of strategies adjusted to prevailing socio-economic, environmental and climatic conditions. The local stakeholders (e.g. Ezemvelo KZN Wildlife, DEA and DWS) are in need of up-to-date information pertaining to the existing biological resources, their conservation status and threats to their sustainability in the Phongolo floodplain. The information from this integrated study will therefore assist the stakeholders in meeting their mandates to establish conservation plans for the ecologically threatened species in the Phongolo floodplain and maintain the socio-ecological functions of the system. These management interventions will aim to contribute to the sustainable maintenance of the ecological services of this unique ecosystem, viz. the importance of the floodplain to the society, economy and health. Sustainable maintenance of the Phongolo floodplain

system through EFR could aid in reducing conflicts associated with the separation of biodiversity conservation and development of the local communities, such as the Tembe Thonga people, who derive ecosystem services from natural ecosystems.

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2 STUDY AREA AND SITE SELECTION

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2.1 Introduction

The focus area of this study is the Phongolo River, the floodplain and its associated pans immediately downstream of the Pongolapoort Dam. The area follows the river in a north-easterly direction towards the Usutu River that forms the border between South Africa and Mozambique. Part of the study area included the Ndumo Game Reserve and an important tributary of the system, the Ngwavuma River.

The site selection process for this study was based on available historical data, current impacts and representation of the ecoregions. The initial selection process (August 2012) was followed by a ground-truth survey in November 2012 and April 2013 during which the suitability of the sites was investigated. As a result, a total of 13 sites were selected and it is important to note that the study area falls within two ecoregions, namely the Lebombo Upland (Ecoregion 12) and Lowveld (Ecoregion 3) Ecoregions (Figure 2.1), with the sampling sites shown in Figure 2.2.

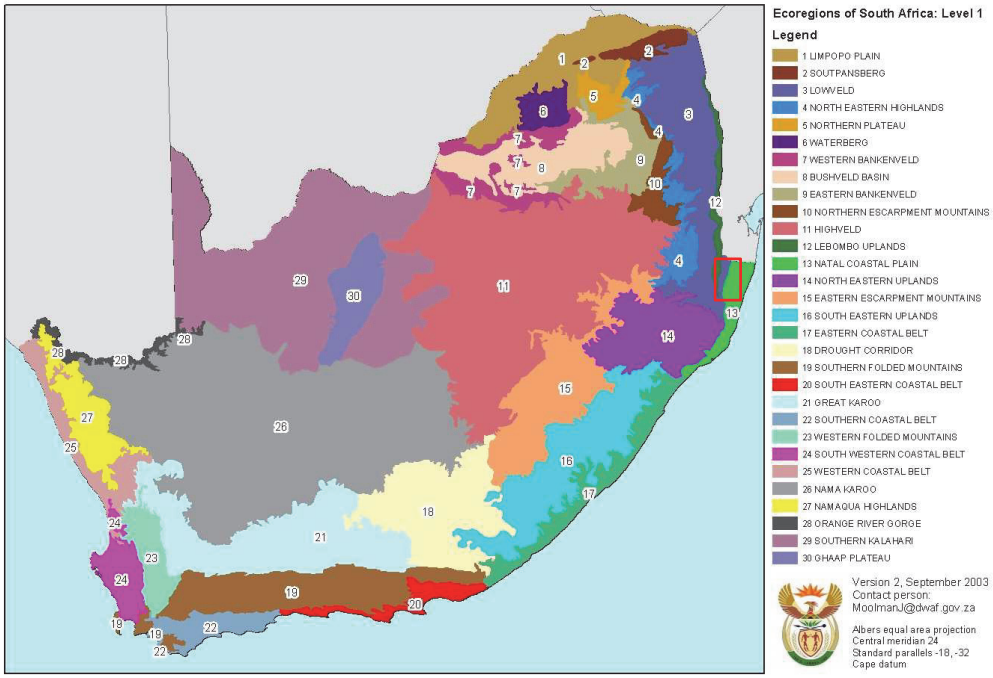


Figure 2.1: A map of the ecoregions within South Africa. Red rectangle indicates the ecoregions of this study.

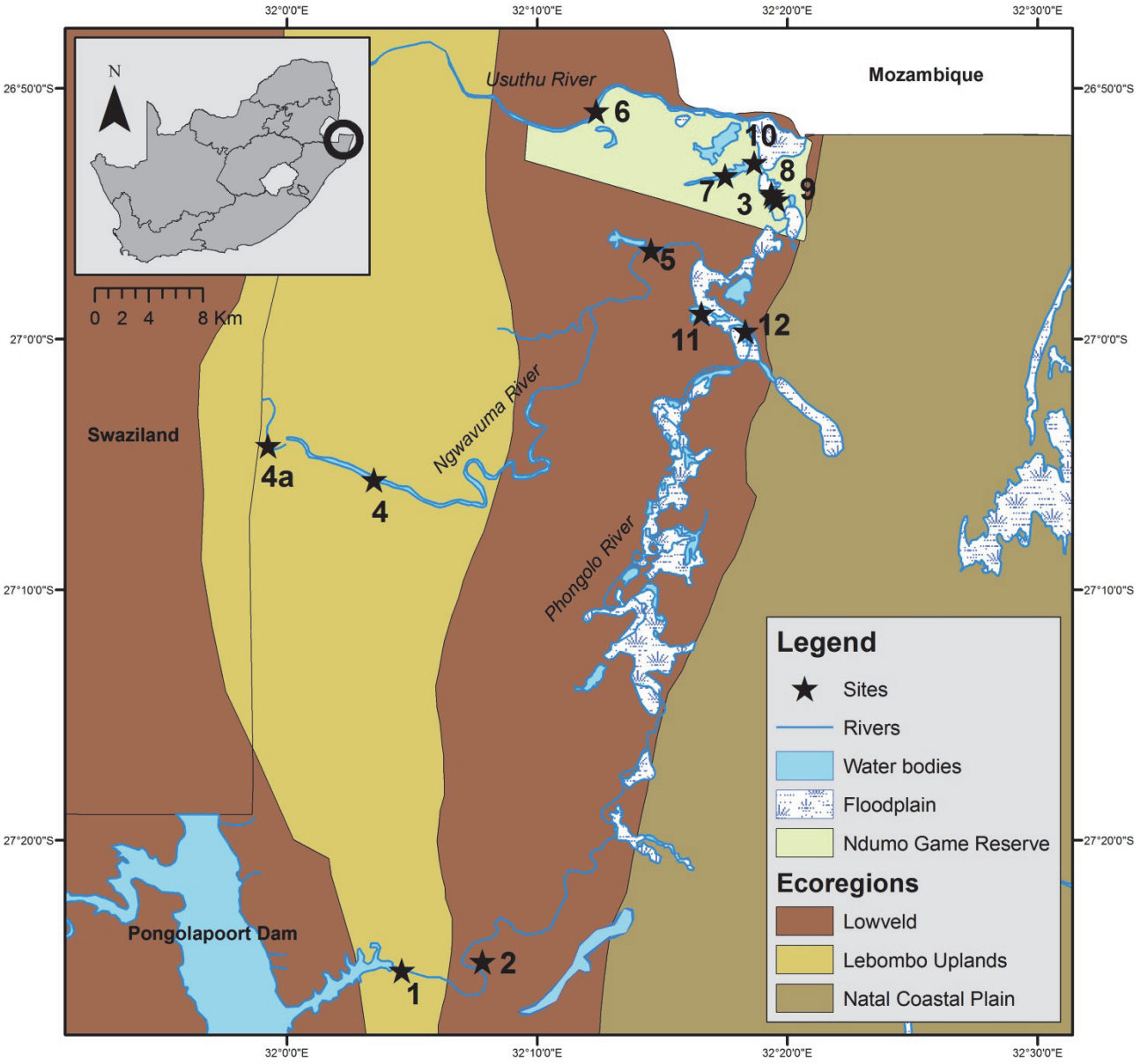


Figure 2.2: The map of the study area indicating the selected sites for this study, indicating the ecoregions associated with each site.

The upstream sites along the Phongolo River (Sites 1 and 2) were selected to determine the water quality and diversity just below the Pongolopoort Dam and the Ngwavuma River (Site 4a) to represent a tributary not impacted by the dam. Sites 1, 4 and 4a also represent conditions in the Lebombo Uplands Ecoregion. The sites downstream in the Phongolo River (Sites 3 and 8) and Ngwavuma River (Sites 4 and 5) were selected to determine anthropogenic impacts whilst Site 6 in the Usutu River was selected as a reference site for this region. This site can then be used to compare information with sites in the Phongolo River that may be impacted by the above-mentioned

stressors in order to determine changes along the ecoregion. Sites 2, 3 and 4 to 12 represents conditions in the Lowveld Ecoregion.

2.2 Site distribution

2.2.1 Sites in the Lebombo Uplands Ecoregion

A total of three sites along the two rivers were selected to represent this ecoregion. Site 1 is located on the Phongolo River immediately below the dam wall (Figure 2.2) with two sites on the Ngwavuma River. The first site (Site 4a) was located 5 km downstream of the South Africa-Swaziland border and the second site (Site 4) was approximately 13 km downstream on the Ngwavuma River.

2.2.2 Sites in the Lowveld Ecoregion

A total of ten sites were selected in this ecoregion, and these comprised five pan sites and four river sites with one site located at the outflow of a pan. Four of these pans are located in the Ndumo Game Reserve and two outside the reserve. The three river sites are along the Phongolo (Site 2), Ngwavuma (Site 5) and Usutu (Site 6) Rivers.

Site 7 is located on the Nyamithi Pan in the Ndumo Game Reserve and it was selected to determine the health status of selected species. Site 3 on the Phongolo River is located in the Ndumo Game Reserve and is at the pump station which provides the camp with water. This site was selected to allow a comparison between fish of the Phongolo River, from inside and outside the Ndumo Game Reserve, as well as between fish from the river and fish from the pans. Both Sites 8 and 9 are pans located close to Site 3. During high flow these pans are connected to the Phongolo River. Site 10 is where Nyamithi Pan is connected to the Phongolo River and was selected to determine the water quality changes associated with outflows into the river as well as possible migrations of fish into the pan and vice versa. Interesting at this site the water and go both directions. During high flow periods of the Phongolo River the water flows here into Nyamithi Pan and during low flow periods the water from the pan flow into the river. Site 6 on the Usutu River was the only site on this river system and was regarded as a reference site to previous work done on the Phongolo River system. This site is a River Health Programme site (W5USUT-ABERC) and therefore some historical data are available. The data from this site can be used to better understand the contribution of the Usutu River with regards to fish diversity and possible alien species introduction into the Phongolo River.

Site 11, Nomaneni Pan, and Site 12, Bumbe Pan, are located outside the Ndumo Game Reserve and were selected to determine the impact of human exploitation on the fish communities within these pans. Data obtained from these sites can be used to compare with data from the Ndumo Game Reserve to determine the effect of human impacts on the fish communities within these water bodies.

All the different habitats at each site were sampled. These habitats were classified based on the velocity and depth parameters as determined by Kleynhans (2007). Within each of these parameters the extent of the potential habitat for the fish, such as substrate, overhanging vegetation, undercut banks, rapids, riffles and backwater pools, was estimated and scored. Fish in these habitats at all the sites were sampled according to the protocol of Kleynhans (2007).

2.3 Site description

2.3.1 Site 1 (Phongolo River)

Site 1 (Table 2.1 and Figure 2.3) is situated immediately downstream of the Pongolapoort Dam wall approximately 200 m from the impoundment. Changes to this site can be attributed to the flood releases from the impoundment. During the low-flow season a regulated flow of 8 m/s is maintained but during the high-flow season volumes of 600-800 m/s can be released. Therefore this section of the river is greatly impacted by the turbulent fast-moving water released from the dam. The habitat of this site has been altered by the turbulent flow from the dam and thus consists predominantly of coarse-grained alluvial material such as rocks and cobbles. A series of vegetated islands are present at this site, but very little fine-grained alluvial sediment is observed.

Table 2.1. Summary of the ecologically important features of Site 1 and the sampling method applied.

Site 1	
River:	Phongolo
Method:	Electro-fishing/7 m seine net/angling
GPS coordinates:	S27 25 12.3 E32 04 35.6
Depth:	250-500 mm (during base flow conditions)
Substrate:	Boulders/cobbles/riffles
Habitat:	Riffle rapids/backwater pools/marginal vegetation
Vegetation:	Western Maputaland Clay Bushveld (Mucina and Rutherford, 2006)

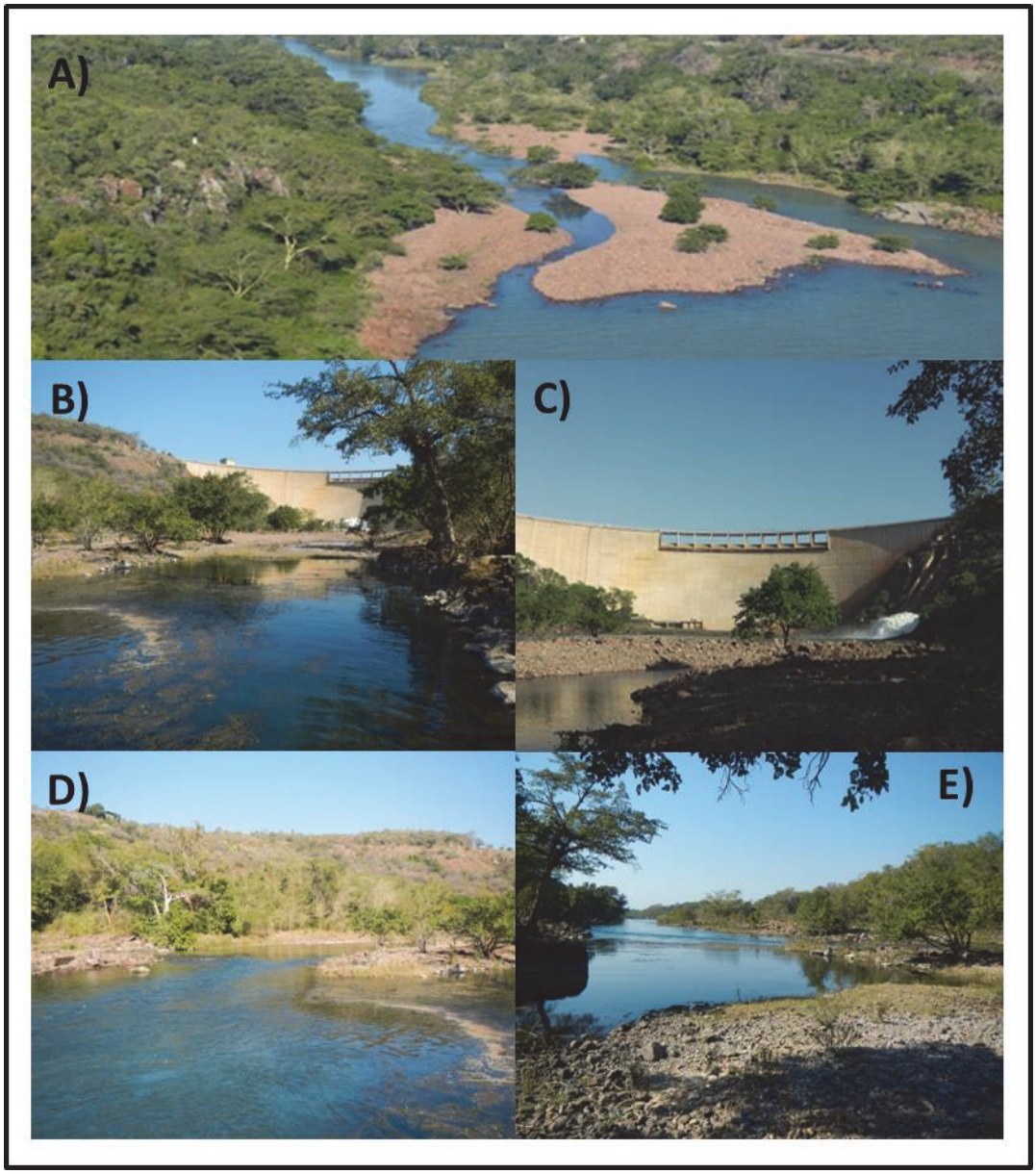


Figure 2.3. A) An aerial photo taken from the dam wall, B-C) upstream view of the site illustrating the backwater pools, D-E) downstream view of the site illustrating the riffle section of the river.

2.3.2 Site 2 (Phongolo River)

The second site (Table 2.2 and Figure 2.4) is located approximately 12 km downstream of the impoundment just as the river enters the Lowveld Ecoregion. There is a riffle section, a backwater pool and a rapid at the downstream end of the site. During base flow conditions the flow at this site is slower than at Site 1 because of the decrease in slope. The backwater pool has aquatic vegetation and there are vegetated side bars. A large area of the river bank (2 ha) is used for sand-mining and there are agricultural activities in the surrounding areas, e.g. sugar cane farming.

Table 2.2. Summary of the ecologically important features of Site 2 and the sampling method applied.

Site 2	
River:	Phongolo
Method:	Electro-fishing/angling/7 m seine net
GPS coordinates:	S27 24 50.8 E32 07 49.0
Depth:	700 mm (during base flow conditions)
Substrate:	Sand/pebbles/cobbles/boulders
Habitat:	Riffles, backwater, rapids, marginal vegetation
Vegetation:	Western Maputaland Clay Bushveld (Mucina and Rutherford, 2006)

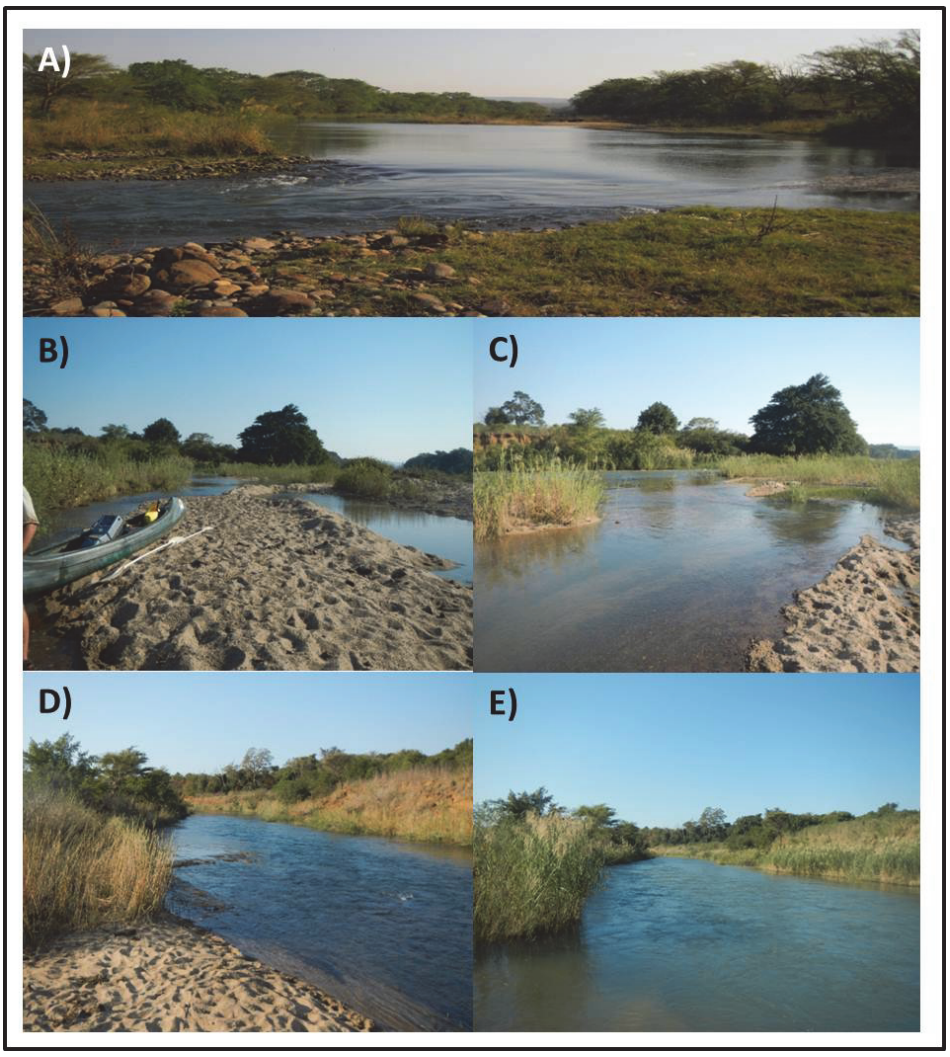


Figure 2.4. A) Upstream view illustrating riffles on the left and a pool area on the right, B-C) backwater pools with slow-flowing water, D-E) downstream view of the site.

2.3.3 Site 3 (Phongolo River – pump station)

This site (Table 2.3 and Figure 2.5) is located approximately 1.5 km north-east of the Ndumo Game Reserve camp site. It is situated at the pump station that provides water to the camp site from the Phongolo River. The overall condition of this site was observed to be generally good. Erosion along the banks does occur and can be attributed to the flood releases during summer months, although the velocity of the water is lower at this site during base flow conditions because farmers abstract water for irrigation purposes. The substrate of this site is predominantly mud and silt with no cobbles or rocks. There are many backwater pools present as well as vegetated bars and islands.

Table 2.3. Summary of the ecologically important features of Site 3 and the sampling method applied.

Site 3	
River:	Phongolo
Method:	35 m seine net
GPS coordinates:	S26 53 29.7 E32 17 30.9
Depth:	1 000-1 500 mm (during base flow conditions)
Substrate:	Sand/silt
Habitat:	Open water, secluded bays
Vegetation:	Lowveld Riverine Forest (Mucina and Rutherford, 2006)

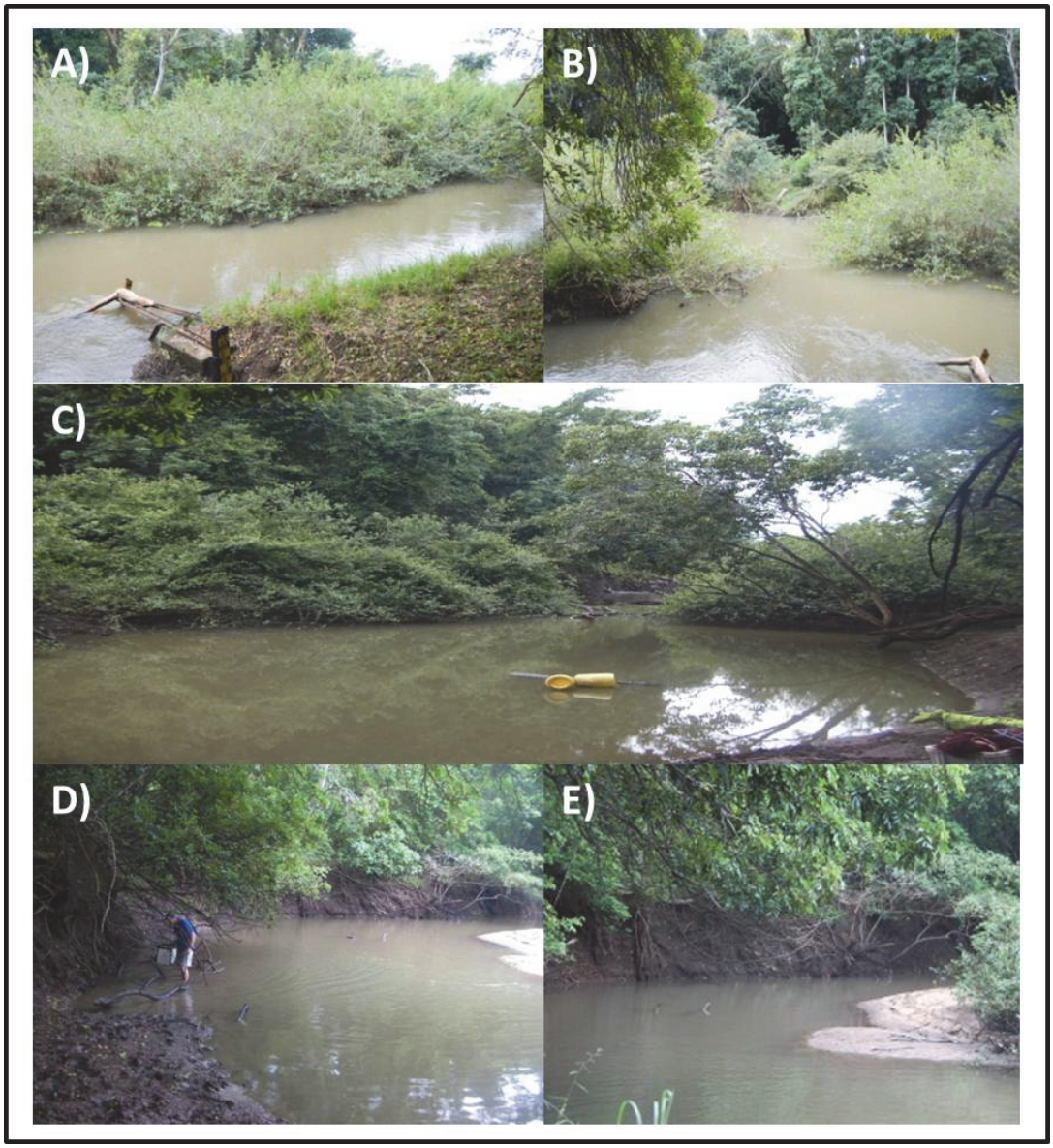


Figure 2.5. A-B) Photos taken upstream of the pump house at Site 3, C) section of the river used for water abstraction for camp-site water supply, D) downstream view illustrating the muddy substrate and erosion along the left bank, E) steep banks on the left bank due to erosion.

2.3.4 Site 4a (Upper Ngwavuma River)

This site (Table 2.4 and Figure 2.6) is located on the Upper Ngwavuma River about 1.4 km east of the Swaziland and South African border. The site consists predominantly of bedrock and boulders with pools and riffles. Further downstream the river has a flat sand bed. There are limited direct impacts at this site, as it is very difficult to get to the site. The only observable impact on this site was the burnt vegetation on the steep slope adjacent to the site which can lead to siltation.

Table 2.4. Summary of the ecologically important features of Site 4a and the sampling method applied.

Site 4a	
River:	Ngwavuma
Method:	Electro-fishing
GPS coordinates:	S27 4 15.93 E31 59 14.48
Depth:	250-500 mm (during base flow conditions)
Substrate:	Bedrock/boulders/cobbles/sand
Habitat:	Riffles, backwater, rapids, marginal vegetation
Vegetation:	Western Maputaland Clay Bushveld (Mucina and Rutherford, 2006)

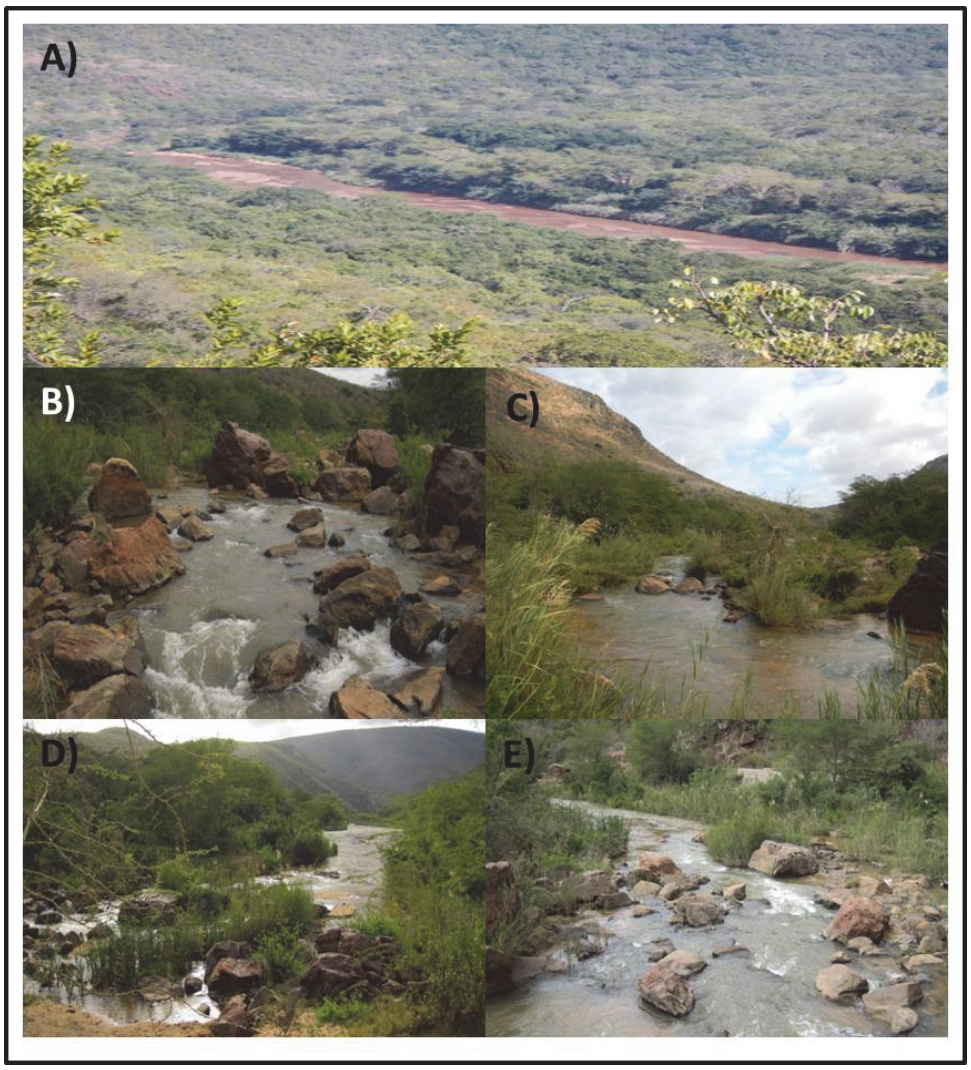


Figure 2.6. A) An aerial view of the Upper Ngwavuma River as it enters South Africa from Swaziland, B-C) upstream view of the site illustrating the large boulders that dominate this site, D-E) downstream view of the site illistrating the boulders and sand substrate at this site.

2.3.5 Site 4 (Middle Ngwavuma River)

This site (Table 2.5 and Figure 2.7) is situated on the Middle Ngwavuma River and is about 12.5 km downstream of Site 4a. The site has marginal vegetation along the banks and the river bed consists mainly of a sand and mud. Building rubble was also observed in the river. There is a bridge crossing the river and extensive sand-mining and brick-making activities along the banks of this stretch of the river. People use this site for water abstraction and for washing clothes and cars. Other impacts include trampling, grazing, cultivation and infrastructure development and can be associated with the erosion on site.

Table 2.5. Summary of the ecologically important features of Site 4 and the sampling method applied.

Site 4	
River:	Ngwavuma
Method:	Electro-fishing
GPS coordinates:	S27 05 36.93 E032 03 28.67
Depth:	250-500 mm
Substrate:	Cobbles/sand and silt
Habitat:	Riffles, backwater, rapids, marginal vegetation
Vegetation:	Western Maputaland Clay Bushveld (Mucina and Rutherford, 2006)

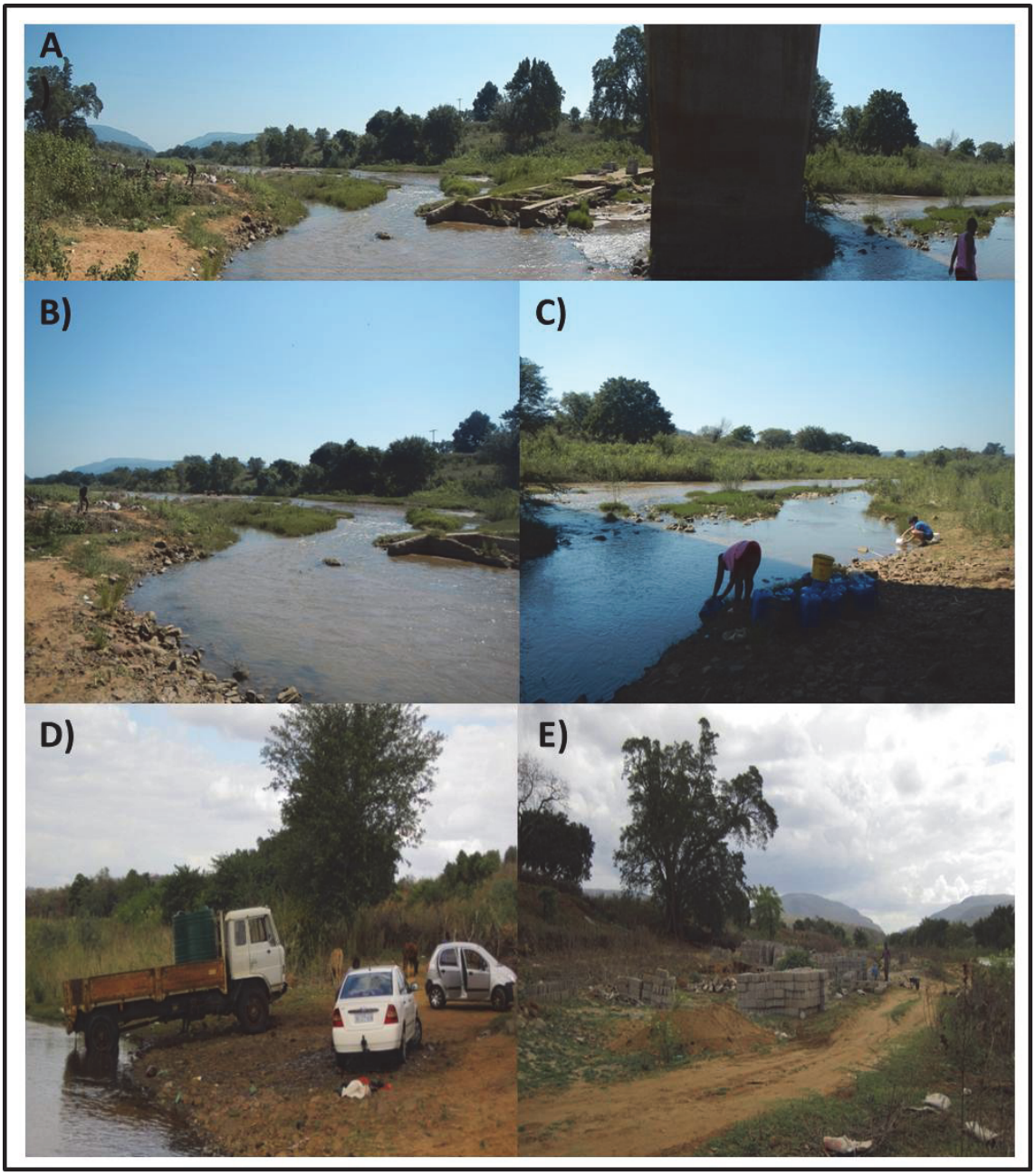


Figure 2.7. A) 180° view of the site with a view of the new bridge crossing and the collapsed old low-water bridge, B) upstream view illustrating vegetated islands and bars, C) downstream view of the river with vegetated islands and bars with local people using the river to wash their clothes, D) water abstraction and washing of cars, E) brick-making and sand-mining activities.

2.3.6 Site 5 (Lower Ngwavuma River)

Site 5 (Table 2.6 and Figure 2.8) is situated on the Lower Ngwavuma River just before it flows into the Phongolo River. It is located approximately 2 km from the Ndumo Village downstream of a culvert that crosses the river. The river flows through three pipes which channelize the flow. The site mainly consists of rocks, mud and sand. The river banks along this stretch of river are eroded.

Impacts on this site can be attributed to the wood collection in the riparian zone and trampling in the area due to agriculture activities along the river banks. These impacts along with the summer floods may be responsible for the extensive erosion at this site (Figure 2.8 E-F).

Table 2.6. Summary of the ecologically important features of Site 5 and the sampling method applied.

Site 5	
River:	Ngwavuma
Method:	Electro-fishing
GPS coordinates:	S26 56 27.65 E32 14 33.00
Depth:	500 mm
Substrate:	Rocks
Habitat:	Riffles, backwater, undercut banks, root wads
Vegetation:	Lowveld Riverine Forest (Mucina and Rutherford, 2006)



Figure 2.8. A-B) Upstream views of the Lower Ngwavuma River illustrating the three pipes that convey the water under the bridge and the dominant substrate of rocks and cobbles, C) downstream view as seen from the bridge, D) approximately 60 m downstream of the bridge an open channel with a sandy substrate, E-F) examples of the erosion at this site.

2.3.7 Site 6 (Usutu River)

Site 6 (Table 2.7 and Figure 2.9) is located on the Usutu River approximately 20 km from the camp site in the Ndumo Game Reserve just downstream of the Red Cliffs picnic site. The site is dominated by a single wide channel with a sandy substrate. There are sand bars in the middle of the channel which divide the channel during low flows but no vegetated islands are present. This river forms the border between South Africa and Mozambique. The southern bank (South Africa) is dominated by tall indigenous reeds during high flow.

Table 2.7. Summary of the ecologically important features of Site 6 and the sampling method applied.

Site 6	
River:	Usutu
Method:	Electro-fishing
GPS coordinates:	S26 52 58.04 E32 18 41.03
Depth:	250-500 mm
Substrate:	Sand, silt
Habitat:	Undercut banks
Vegetation:	Western Maputaland Clay Bushveld (Mucina and Rutherford, 2006)

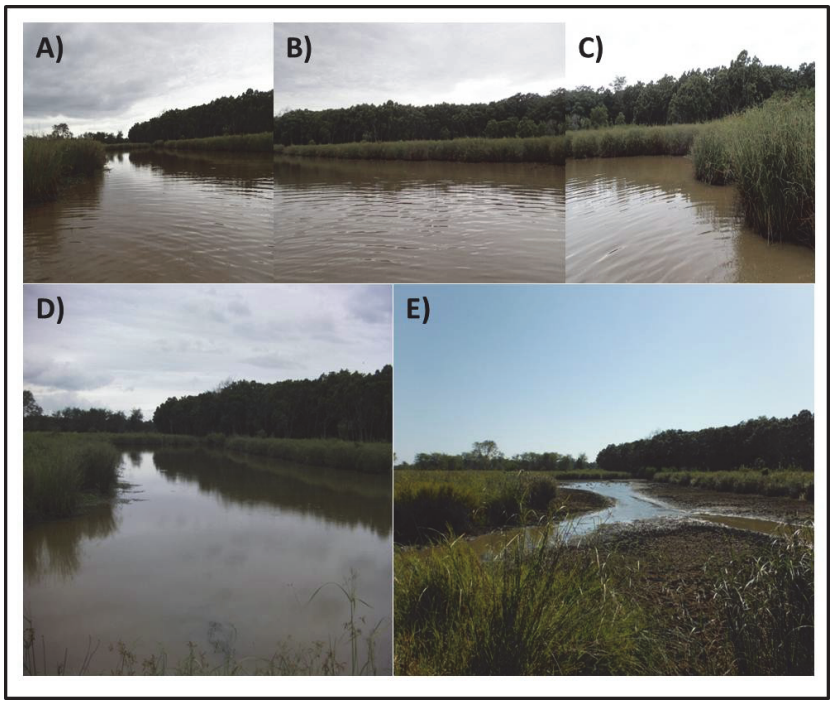


Figure 2.9. A) 180° view of the Usutu River, B-C) upstream views of the river illustrating the wide channel with the sandy substrate, D-E) downstream view of the wide channel with dense vegetation.

2.3.8 Site 7 (Nyamithi Pan)

Nyamithi Pan (Table 2.8 and Figure 2.10) is situated approximately 4 km north-east of the main entrance to Ndumo Game Reserve and is the second largest pan within the borders of the reserve. It is a perennial pan with a sandy substrate and mud. The depth range from 1 m to 1.5 m during base flow periods. The north-western side of the pan is the periodically flooded zone with grass in the dry season and a large number of fever trees (*Vachellia xanthophloea*). The south-eastern side of the pan has steeper banks and is predominantly vegetated by Lowveld Riverine Forest.

Table 2.8. Summary of the ecologically important features of Site 7 and the sampling method applied.

Site 7	
River:	Phongolo
Method:	35 m seine net
GPS coordinates:	S26 53 29.7 E32 17 30.9
Depth:	1 000-1 500 mm
Substrate:	Sand/silt
Habitat:	Open water, secluded bays
Vegetation:	Lowveld Riverine Forest (Mucina and Rutherford, 2006)

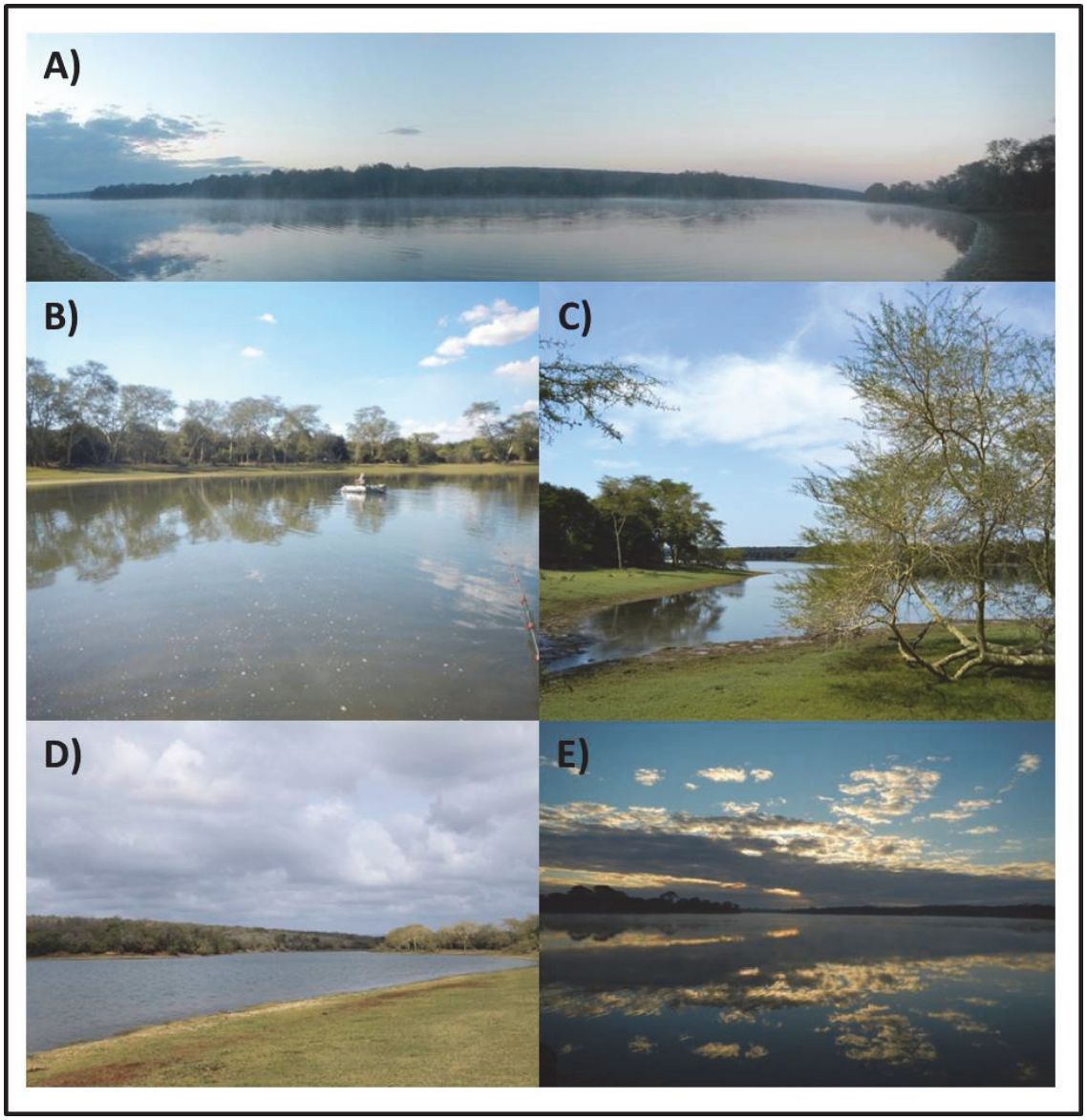


Figure 2.10. A) 180° view of Nyamithi Pan, B) a view of the north-western side of the pan with flat banks which are dominated by grass and fever trees, C) one of the many bays formed on the north-eastern site of the pan, D) illustration of the contrast between the north-western bank (grass) and the south-western bank (far side) that is vegetated by Lowveld Riverine Forest, E) view of the large open body of water.

2.3.9 Site 8 (Unnamed floodplain pan 1 in NGR)

This site (Table 2.9 and Figure 2.11) is a pan in close proximity to Site 3 and is located approximately 250 m north and downstream. This is a temporary pan and fills up with water during the high-flow season when water is released and it is connected to the Phongolo River with a small channel. The edges of the pan are vegetated by tall reeds and grass. This site was selected to represent a temporary floodplain pan within the Ndumo Garme Reserve that are connected to the Phongolo with a chanal. The small channel ensure longer water retention than those pans not connected.

Table 2.9. Summary of the ecologically important features of Site 8 and the sampling method applied.

Site 8	
River:	Phongolo
Method:	35 m and 7 m seine net
GPS coordinates:	S26 88 27.7 E32 31 13.9
Depth:	700-1000 mm (at retention level)
Substrate:	Silt
Habitat:	Water column and marginal vegetation
Vegetation:	Lowveld Riverine Forest (Mucina and Rutherford, 2006)

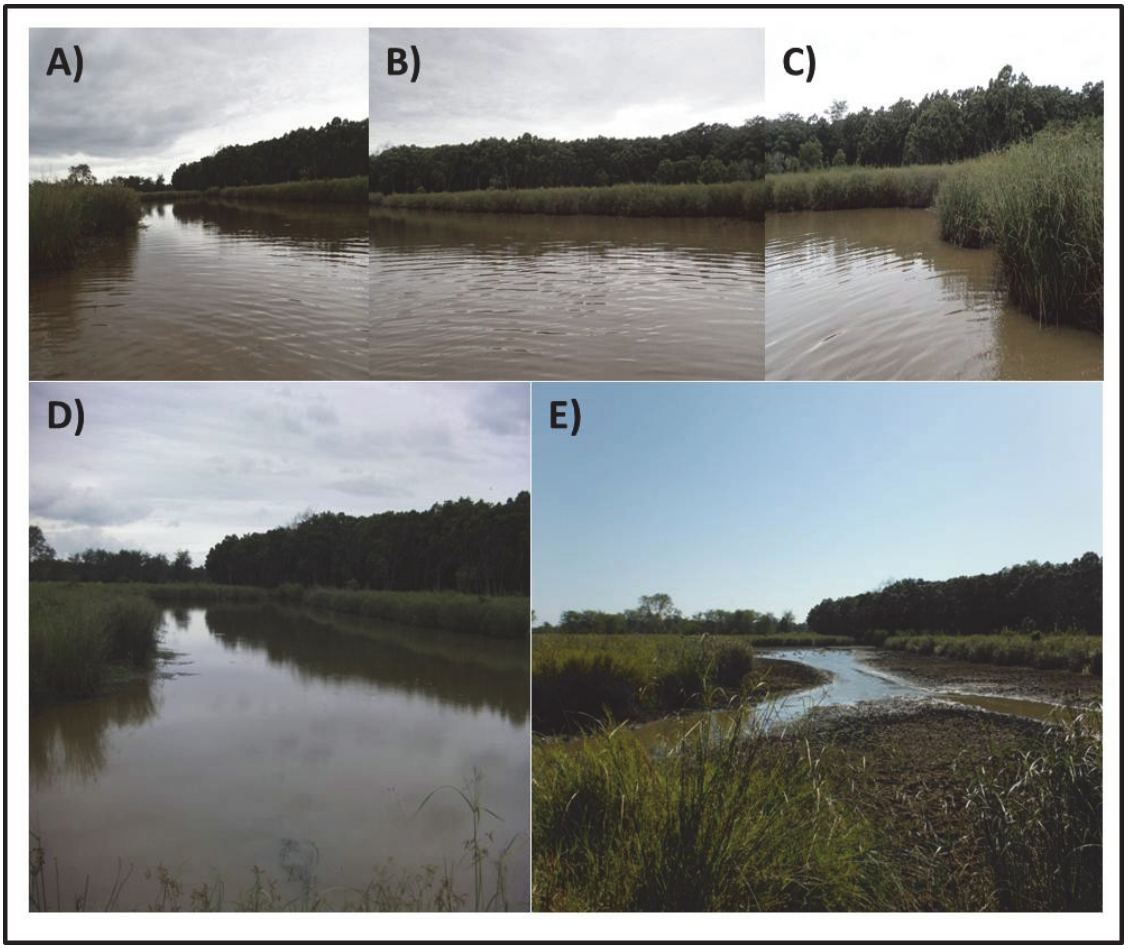


Figure 2.11. A-C) views of the south side of the pan illustrating that tall reeds are the dominant vegetation along the banks, D) complete view of the entire pan when flooded, E) view of the pan before the next flood.

2.3.10 Site 9 (Unnamed floodplain pan 2 in NGR)

This site (Table 2.10 and Figure 2.12) is a pan in close proximity to Site 3 and is located approximately 600 m south-east and upstream. This is a temporary pan and fills up with water during flooding when the Phongolo River overflow its banks. There is no clear channel that connect this pan with the Phongolo River as in pan 1 (see above). Its water retention is also shorter than that of pan 1. The edges of the pan are vegetated by tall reeds and grass.

Table 2.10. Summary of the ecologically important features of Site 9 and the sampling method applied.

Site 9	
River:	Phongolo
Method:	35 m and 7 m seine net
GPS coordinates:	S26 54 27.90 E32 19 35.04
Depth:	500 mm (when flooded)
Substrate:	Silt
Habitat:	Water column and marginal veg.
Vegetation:	Lowveld Riverine Forest (Mucina and Rutherford, 2006)

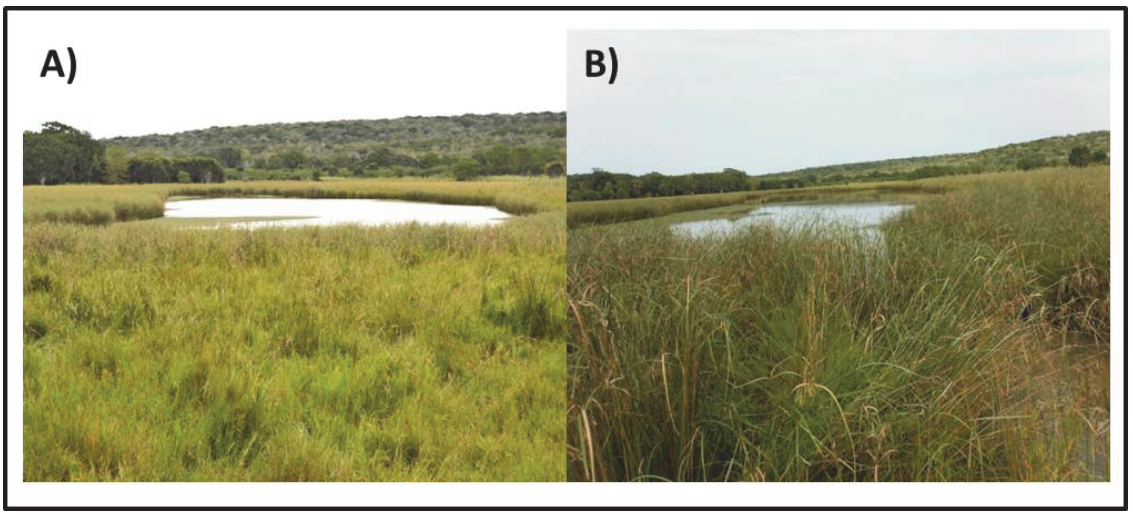


Figure 2.12. A) View of the entire pan, B) closer view of the pan illustrating the dominant vegetation (tall reeds)

2.3.11 Site 10 (outflow of Nyamithi Pan)

This site (Table 2.11 and Figure 2.13) is located at the channel that connects Nyamithi Pan with the Phongolo River. There is a causeway that regulates flow from the pan into the river. On the Nyamithi Pan Tside of the causeway is a large pool approximately 1-1.5 m deep during base flow periods. During flood events in the Phongolo River the causeway is drowned out and water backs up into the pan. This allows upstream migration of fish into the pan. Erosion on the banks on both sides of the causeway can be attributed to both the flooding into the pan and the flood recession when water flows out of the pan and has resulted in steep vertical banks on both sides. During the low flows the water from the pan flows across a boulder/cobble bed which can be regarded as a riffle area.

Table 2.11. Summary of the ecologically important features of Site 10 and the sampling method applied.

Site 10	
River:	Phongolo
Method:	35 m seine net/fyke nets/electro-fishing
GPS coordinates:	S26 88 05.5 E32 31 17.8
Depth:	1 000-1 500 mm (during base flow periods)
Substrate:	Cobbles/silt
Habitat:	Riffles, pools, undercut banks
Vegetation:	Lowveld Riverine Forest (Mucina and Rutherford, 2006)

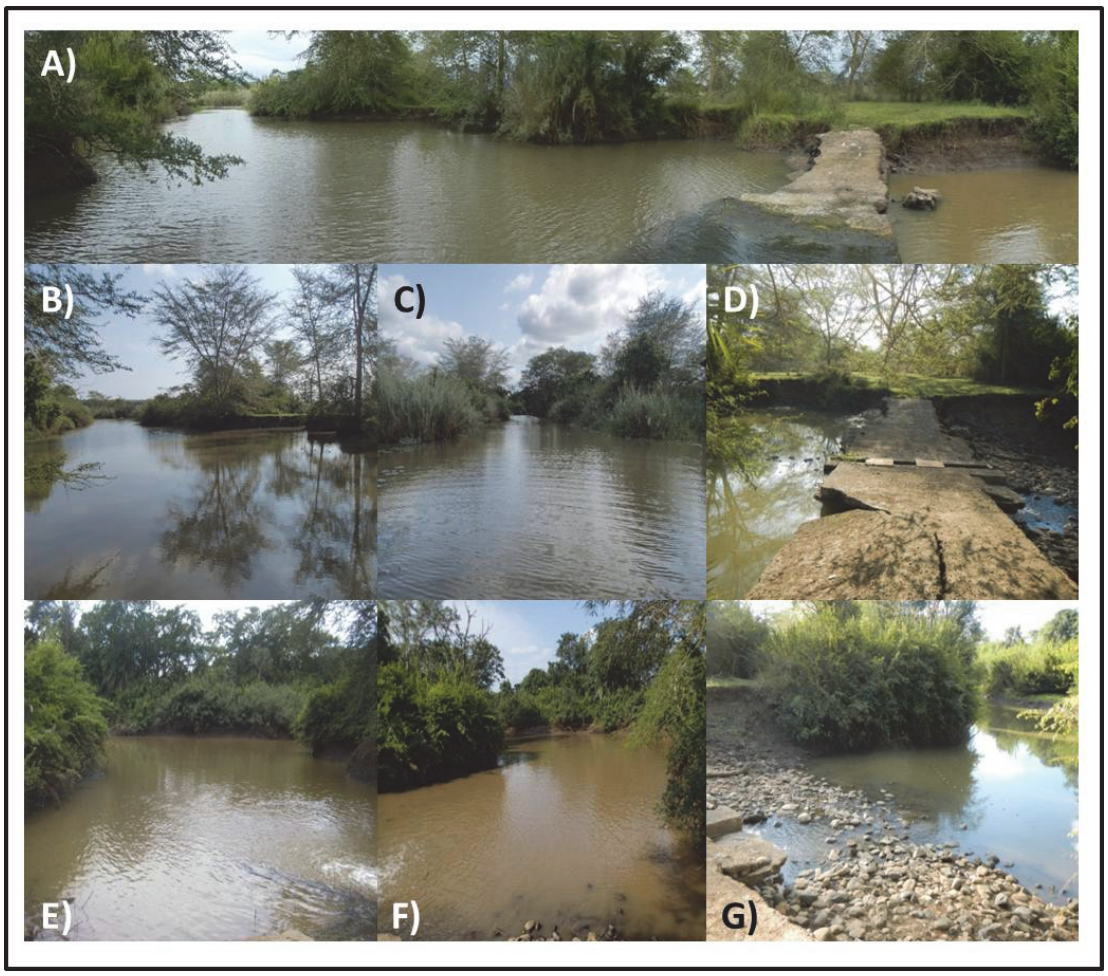


Figure 2.13. A) 180° View of the outflow of Nyamithi Pan illustrating the pan south of the causeway and the channel that connects Nyamithi Pan with the Phongolo River on the northern side, B) Upstream view of the pan from the causeway illustrating the deep pool area, C) a downstream view towards the causeway, D) a photo of the collapsed causeway illustrating the eroded steep banks on both sides of the bridge, E-F) downstream view from the bridge illustrating the pool area created by the Phongolo River during high flow season, G) exposed rocks and cobbles on the right-hand side (Phongolo River) of the causeway, during low flow.

2.3.12 Site 11 (Nomaneni Pan)

This site (Table 2.12 and Figure 2.14) is located outside the Ndumo Game Reserve and is close to an informal settlement. It is a shallow muddy pan with aquatic vegetation. This is also a temporary pan that is connected to the Phongolo River during flood, but is disconnected from the river during the low flows. People from the community use this pan for washing, subsistence fishing, water abstraction and agriculture. Animals graze the grassland around the pan.

Table 2.12. Summary of the ecologically important features of Site 11 and the sampling method applied.

Site 11	
River:	Phongolo
Method:	35 m seine net
GPS coordinates:	S26 59 13.19 E32 16 21.38
Depth:	250-500 mm
Substrate:	Silt
Habitat:	Water column, aquatic vegetation
Vegetation:	Lowveld Riverine Forest (Mucina and Rutherford, 2006)

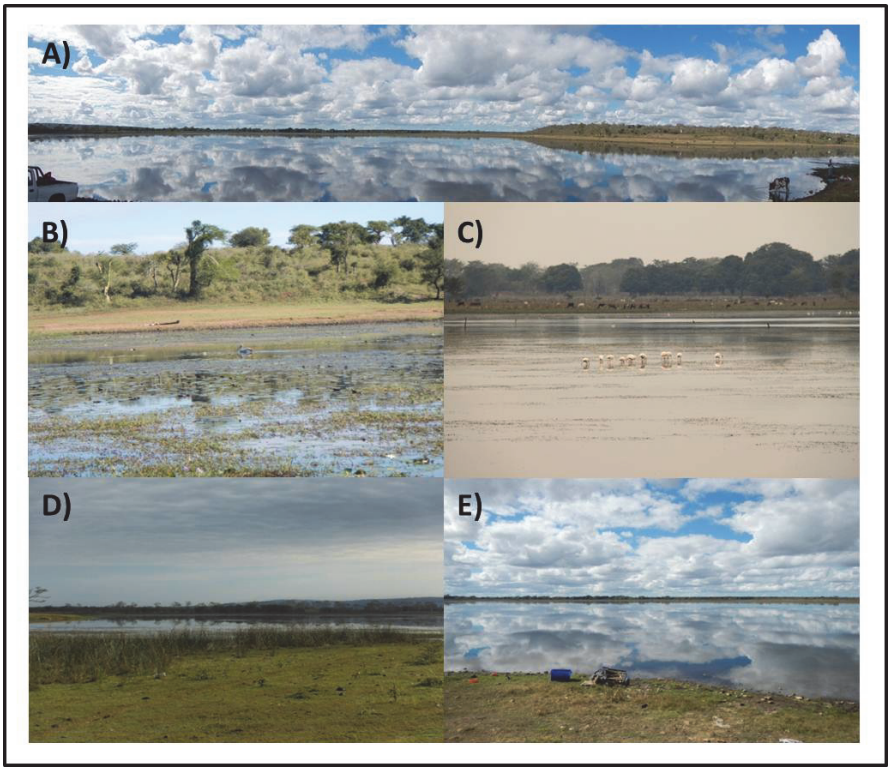


Figure 2.14. A) 180° view of Nomaneni Pan, B-E) illustrating the extent of the aquatic vegetation.

2.3.13 Site 12 (Bumbe Pan)

Bumbe Pan (Table 2.13 and Figure 2.15) is situated 2 km south-east of Nomaneni Pan and they are interconnected via Ngodo Pan. Bumbe Pan is a perennial pan and gets its water from the Phongolo River during the high-flow season. The impacts are similar to those observed at Site 11. Bumbe Pan is a shallow muddy pan with extensive aquatic vegetation. At this site, the riparian vegetation is less impacted, but wood harvesting and stock trampling and grazing of vegetation can cause erosion of the banks.

Table 2.13. Summary of the ecologically important features of Site 12 and the sampling method applied.

Site 12	
River:	Phongolo
Method:	7 m seine net
GPS coordinates:	S26 59 13.19 E32 16 21.38
Depth:	250-500 mm
Substrate:	Silt
Habitat:	Water column, aquatic vegetation
Vegetation:	Lowveld Riverine Forest (Mucina and Rutherford, 2006)

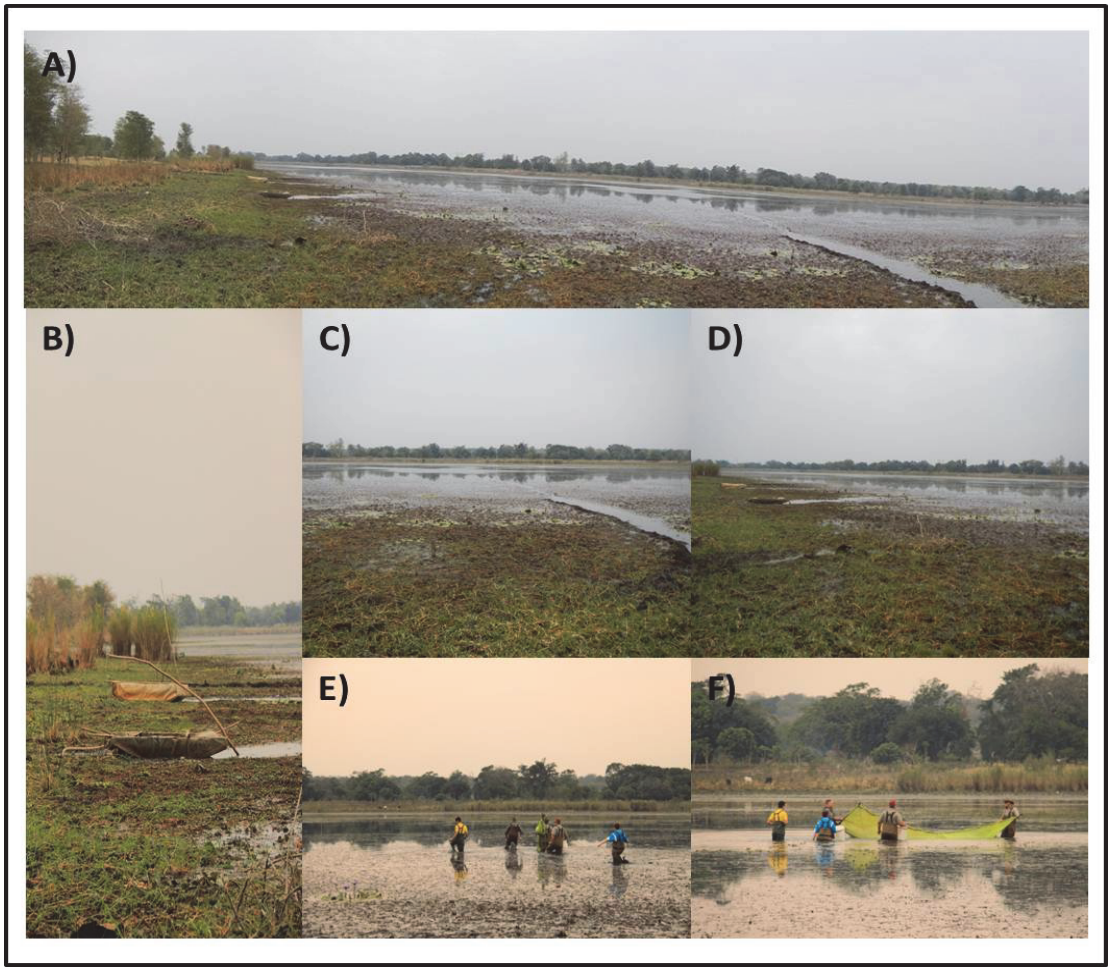


Figure 2.15. A) 180° view of Bumbe Pan, B) boats used by the local people for fishing and agriculture, C-D) illustrates that all the riparian vegetation has been removed and the channel is used for water abstraction, E-D) gives an indication of how shallow this pan is.

2.4 Surveys

A total of five surveys (Table 2.14) were carried out in the period from November 2012 to April 2014 to include data from the different seasons as well as of high-flow and low-flow periods.

Table 2.14. Summary of surveys conducted from 2012 to 2014.

Survey No.	Date	Purpose
1	13th to 20th November 2012	Reconnaissance survey
2	15th to 24th April 2013	High flow
3	27th July to 4th August 2013	Low flow
4	9th to 15th September 2013	Low flow
5	6th to 14th April 2014	High flow

2.5 Materials and methods

2.5.1 Fish collection

A wide variety of sampling techniques were used for the different habitats that ranged from still-standing water to fast-flowing rivers. Angling was used in order to target specific species such as *Hydrocynus vittatus* and *Clarias gariepinus*. Two sizes of fyke nets were used in the river to sample the fast-flowing water as well as the backwater pools and backwater slides (800 mm and 1 500 mm hoops) (Figure 2.16 A-B). These nets were serviced at 12-hour intervals and were left in the water during the entire survey. A 7 m seine with a 1 mm mesh size was mostly used in the backwater pools of rivers (Figure 2.16 C-D) and a 35 m seine with a 10 mm mesh size was used in Nyamithi and Nomaneni Pan (Figure 2.16 E-F). Electro-fishing with a Smith-Root© electro-shocker was used at all of the sites to target smaller species that are often not caught using the above-mentioned methods (Figure 2.16 G-H).

Fish at all the sites were sampled according to the habitat specific protocol described by Kleynhans (2007). Habitats include: slow deep, slow shallow, fast deep, fast shallow. Fish from the different habitats were kept separate for analysis, because if a certain habitat cannot not be sampled it is important to make conclusions within this limitation. This means that if one habitat was not sampled the species that would predominantly occur in this habitat must be excluded from the assessment in terms of the species that would occur in that region according to the reference condition.

All the individuals caught were identified using the key provided in Skelton (2001) and the total length (TL) and standard length (SL) were measured on a measuring board. Fish diversity and abundance data were used to calculate the fish response assessment index (FRAI) scores as well as the community structure at all the sites. The fish community data were compared to historical data. Specimens of a number selected species were retained for analysis. All other specimens were released back at the site of capture.



Figure 2.16. A) Photograph of a standard fyke net (80 cm hoop), B) an example of what a fyke net looks like in a backwater pool, C) a group of scientists identifying fish in the field, D) photograph of the 7 m minnow seine net used during these surveys, E) an example of how this net is used, F) example of a successful pull using the 7 m seine net, G-H) setting the 35 m seine net

2.5.2 Water quality

In situ physicochemical water quality parameters were measured 10 cm below the surface of the water close to the water's edge (approximately 1 m) at each site using an YSI 9260 water quality meter. The data collected were:

- Temperature (ºC)
- Electrical conductivity (mS/m)
- TDS (mg/L)
- pH
- Dissolved oxygen saturation (%),
- Dissolved oxygen concentration (mg/L)
- Turbidity (NTU)

2.6 Conclusion

The information on the sites and ecoregions will be used in Chapter 4 as it was used to quantify the EcoStatus of the sites related to the reaches in the study area. In addition, the site data will be used in detailed discussions in Chapter 4, 5 and 6.

With regard to the fish sampling methodology (2.5.2), the information of the collected specimens was used for assessing the EcoStatus of fish communities (Chapter 4), the community structure and health of the fish (Chapter 5), the ecotoxicity testing and analysis of selected fish species (Chapter 6) and the discussion of the biodiversity of the Phongolo River and the associated floodplain (Chapter 7).

If specialised methods were employed, these will be discussed in detail in the relevant chapter.

2.7 References

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3 WATER QUALITY ASSESSMENT OF THE PHONGOLO RIVER AND FLOODPLAIN

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3.1 Introduction

According to Van der Laan et al. (2012), deteriorating quality of South Africa's water resources due to the growth in water demand requires an optimal management of this critical resource. Further development along our important rivers can be expected to impact water quality negatively. At a specific point along a river, the quality of water reflects several major influences, including basin lithology, climatic conditions and atmospheric and anthropogenic inputs (Bricker & Jones, 1995; Van der Laan et al., 2012). Anthropogenic impacts such as discharges from waste water treatment works, industrial, discharges via agricultural runoff. Activities that cause streamflow reduction, such as commercial forestry, can also impact negatively on water quality by reducing the dilution capacity of a waterway (Van der Laan et al., 2012).

Increased crop production activities within a catchment often result in higher nutrient concentrations in rivers and impoundments (Heathwaite & Johnes, 1996). Matson et al. (1997) observed that nitrate (NO_3^-) pollution was common in agricultural regions throughout the world. This enrichment can result in eutrophication of these systems. The Organisation for Economic Co-operation and Development (OECD, 1982), defines the eutrophication process as the nutrient enrichment of waters, which results in the stimulation of an array of symptomatic changes, amongst which are increased production of algae and aquatic macrophytes, deterioration of water quality and other symptomatic changes found to be undesirable.

In irrigated agriculture, water of an acceptable quality is required for profitable, sustainable crop production. Irrigation water high in salts can reduce yields significantly, especially in cases where there is poor soil drainage. As crops transpire irrigated water, salts are left behind inevitably leading to a build-up in their concentration. Sustainable production requires the periodic export of these salts from the root zone to prevent salinity referred to as the 'leaching requirement' (Rhoades, 1974). Van der Laan et al. (2012) further stresses that the higher the salt content in the irrigation water, the higher will be the resultant salt concentration in the irrigation return flow. When these salts are washed from agricultural lands back into waterways, a subsequent deterioration in the quality of these receiving water bodies can be expected.

3.1.1 Water quality management in South Africa

Until the 1990s, South Africa focused on developing the water resources for the purpose of water supply and infrastructure management to meet the demands of water for agricultural and industrial development. Prior to the 1990s limited attention was paid to the effect of these development activities on the natural environment, including the water environment (Nomquphu et al., 2007). The hydrological monitoring programmes were focused mainly on surface water quantity than on water quality monitoring. However with the advent of the National Water Act (NWA) of 1998 (Act Number 36 of 1998) has shifted the focus from supply-driven water development to managing a water resource in which ongoing, integrated monitoring and assessment are critical for the management and protection of water resources as stipulated under Chapter 14 of the National Water Act of 1998. These requirements resulted in the emergence of various water quality information requirements that led to the initiation of a number of additional national water quality monitoring programmes, namely:

a) The National Microbial Water Quality Monitoring Programme (NMMP)
b) National Chemical Monitoring Programme (NCMP)
c) The National Eutrophication Monitoring Programme (NEMP)
d) The National Toxicity Monitoring Programme (NTMP)
e) The River Health Programme (RHP)
f) The National Radioactivity Monitoring Programme (NRMP)

According to van Niekerk et.al (2009), the NCMP, which has been operated by DWA over a period of more than 30 years had to be aligned with the requirements of the National Water Act. Until 2003 the NCMP had grown into a large database with no set monitoring objectives or a documented design. The NCMP focused on the suitability of water for irrigation and the nutrient concentrations at flow gauging station and reservoirs. These monitoring efforts were motivated by the fact that significant changes in salinity can have serious implications for a number of water uses, such as irrigation, livestock watering, domestic use, industrial use, biodiversity. The realisation by the Department of Water Affairs and Forestry that the monitoring of EC is insufficient for the detection of long-term changes in water quality and changing legislative requirements as well as increased pressure on freshwater resources led to the design and implementation of additional national monitoring programmes for eutrophication, microbiology, ecosystem health, toxicity and radioactivity to determine the long-term data for trend detection (van Niekerk et.al, 2009).

The review of water quality monitoring and addition of water quality monitoring programmes also stems from the changing dynamics in terms of the approach to water quality management. The

NWA adopts the integrated water resource management (IWRM) principles and as a result makes the distinction between “water quality” and “water resource quality”. As per NWA, water quality refers to chemical, physical and biological characteristics of the water component of the water resource, whereas “water resource quality” encompasses not only the water quality component, but also other aspects of the aquatic ecosystem, such as riparian vegetation, water quantity, and geomorphology (DWAF, 1998; 2004). The NWA therefore introduces various methods of protecting the water resources included in Chapter 3 of the Act. These include the Reserve, resource quality objectives (RQOs) and the classification of significant water resources. The classification process forms the core of these processes.

3.1.2 Ecoclassification

According to Kleynhans and Louw (2008) the ecoclassification or ecological classification refers to the determination and categorisation of the present ecological state (PES) (health) of various biophysical attributes (riparian vegetation, fish, macroinvertebrates) of a river compared to the natural or close to natural reference condition. The purpose of ecoclassification is to gain insight into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the rivers. The state of the river is expressed in terms of biophysical components:

- Drivers (physicochemical, geomorphology, hydrology) which provide a particular habitat; and
- Biological responses (fish, riparian vegetation and aquatic invertebrates).

As described in Kleynhans and Louw (2008), the PES of the river is expressed in terms of various components that are the drivers and biological responses as well as the integrated state, the EcoStatus. When assessing the PES, the ecological importance and sensitivity (EIS) of the river is determined. The ecological importance of the river is an expression of its importance to the maintenance of biological diversity and ecological functioning on local and wider scales. Ecological resilience referred to as sensitivity (or fragility) in Kleynhans and Louw (2008) refers to the system’s ability to resist disturbance and its capability to recover from disturbance once it has occurred. Both biotic and abiotic components of the system are taken into consideration in the assessment of the EIS.

3.1.3 Water quality of the Phongolo River and floodplain

The Pongolapoort (Jozini) Dam impounds the water of the Phongolo River and thus alters the flood also the flow regime downstream. The construction of the dam attracted a number of activities which are also contributing to deteriorating water quality downstream of the dam. The floodplains extend from just downstream of the dam to the confluence of the Phongolo and Usutu Rivers close to the border with Mozambique.

After analysing long-term water quality monitoring data of the Phongolo River system (1999 to 2009), Van der Laan et al. (2012) found that the electrical conductivity (EC)data show an increase in salt concentrations particularly, during the rainy season. Heeg and Breen (1982) found that the quality of the river upstream of the Pongolapoort Dam was significantly affected through saline and nutrient-enriched return flows from large irrigation areas with return flows estimated to be about 21 million m^3 per annum or 10% of the irrigation demand. This is a seasonal phenomenon and it accentuated in the low-flow months when dilution from natural flows is less (Heeg & Breen, 1982).

The important water plant species, *Potamogeton crispus* upon which much of the productivity of the floodplains depends is adversely affected by salt concentrations in excess of 4 000 mg/l and all oligochaete worms and freshwater mussels disappear at these salinities (Heeg & Breen, 1982). The periodic flooding of the floodplain thus serves to reduce the salinity in the pans, levees and depressions, while they in turn play a major role in containing flood waters along the river system.

According to DWAF (2009) the concerns in the Phongolo River and the upper reaches of Pongolapoort Dam are centred on the impacts of abandoned coal mines in the Paulpietersburg area with potential acid mine drainage, and of the irrigation scheme at Pongola. Impacts of pesticides and other agricultural products especially in the Middle and Lower Phongolo River are the main concern (DWAF, 2009). Salinity increases between Pongolapoort Dam and the confluence with the Usutu River were also observed and attributed to irrigation return flows from the Makhathini Irrigation Scheme and seepage of saline groundwater into pans and the river. One of the issues raised was that increased salts due to irrigation could result in elevated sodium concentrations (sodification), which in turn would result in the upward movement of saline water thereby exacerbating the salinity of the systems. The salinity downstream of the Pongolapoort Dam, just before the confluence with the Usutu River is however still regarded to be acceptable (DWAF, 2009).

Electrical conductivity is most commonly used as an indicator of salinity and irrigation water quality classifications while nitrogen and phosphorus are the primary nutrients causing eutrophication

because they are most often the limiting factors for algal growth (Van der Laan et al., 2012). According to these authors, from an EC perspective, irrigation water quality in the system is categorized as “good” at Welgelegen for all seasons, but then deteriorates by the time it reaches Mhlati where it is categorized as “good” for autumn only, and “fair” for spring, summer and winter. Van der Laan et al. (2012) observed a mean EC of 57 mS/m at Mhlati whereas Pongola River was 62 mS/m. For the Pongolapoort Dam downstream of the irrigated region in Pongola, water quality has been reported as ideal but showing deterioration with regards to salinity, and this increase in salinity is attributed to irrigation return flows (DWA, 2009). An increase in the eutrophication at the inflow of the Pongolapoort Dam is attributed to nutrient enrichment via irrigation return flows, and concerns have been raised regarding an emerging new invasive water plant, *Hydrilla verticillata* due to the increased nutrient availability (DWAF, 2009).

It is clear that during the construction of the dam and determination of the releases, consideration of some aspects of resource quality were not part of the planning from the start of the development of Phongolo River system including Pongolapoort Dam, Bivane Dam and associated flood control releases. The focus was to promote agriculture in the vicinity of floodplains, to release quantities of water for irrigation from the dam and later to also release quantities of water to simulate natural conditions. The timing and volume of dam releases were aimed at simulating the natural flows in and out of floodplain and concentrated only on water quantity for the purposes of agricultural (crops and grazing) requirements and did not consider the effect of water quality in the upper and middle Phongolo River (Van der Laan et al., 2012).

The possible impacts of agricultural development in the vicinity of the Pongolapoort Dam and Phongolo River banks upstream, implemented after the construction of the dam, were also highlighted in a series of studies conducted in the area (Heeg & Breen, 1982; DWAF, 1985; 2009; Van der Laan et al., 2012). These have either been conducted at a desktop level or with minimum level of onsite data collection. The impacts of the dam on the ecology and functionality of the floodplains and pans downstream of the dam, their role in regulating water quality as well as the quality of inflows have not been well researched. This information is critical to determine the way forward for sustainability of the river system and to protect the biodiversity of the river system. The DWAF long-term water quality monitoring data which date back to the 1970s have been used to determine the natural water quality conditions of the river system.

3.1.4 Study objectives

The objectives of this chapter are:

- To determine and document historical water quality in the area.
- To determine the current state of water quality upstream and downstream of the Pongolapoort Dam.
- To highlight the Pongolapoort Dam catchment and activities within it.
- To recommend measures towards improving the water quality.
- To determine physicochemical driver assessment index (PAI) for use in generating the Present Ecological State (PES) of the Phongolo River.
- Provide relevant water quality information on the lower Phongolo River for potential inclusion in assessment of risk posed by current levels of water quality variables to suitability for use by humans and aquatic ecosystem.

3.2 Materials and methods

3.2.1 Sample collection

There are 11 DWA monitoring sites within the Phongolo River catchment (i.e. in the vicinity of the Pongolapoort Dam) that form part of the NCMP (Figure 3.1). The water quality data assessed includes: calcium (Ca), chloride (Cl), electrical conductivity (EC), fluoride (F), potassium (K), magnesium (Mg), sodium (Na), ammonium (NH_4), nitrate and nitrite (N as NO_3/NO_2), pH, soluble reactive phosphate (P as PO_4^{3-}) and sulphate (SO_4). The upstream (Middle Phongolo River) water quality data assessed were from stations W4H003Q01 (Phongolo River at Bokfontein/Grootdraai), W4H008Q01 (Phongolo River at M'Hlati), W4H011Q01 (Phongolo River at Mvutshini Estate), 188858 Illovo Sugar Mill (Koppie Alleen upstream of Illovo Sugar Mill discharge on Phongolo River), 188865 (Consol Lelieshoek D/S Illovo Sugar Mill effluent discharge point on Phongolo River) and W4H006Q01 (Phongolo River at Makanes Drift), and downstream (Lower Phongolo River) are W4H007Q01 (Braksloot Spruit at Pongola), W4H009Q01 (Phongolo River at Ndumo Game Reserve), W4R001Q01 (Pongolapoort Dam near the dam wall), W4H013Q01 (Pongolapoort Dam on Phongolo River downstream) and W4H010Q01 (Phongolo River at Lake View/Ndumu (Kangazini). The monitoring frequency is monthly and records for 19 years are available (W4H010Q01 1977 to 1995). Stations W4H006Q01 and W4H011Q01 (Phongolo River at Mvutshini Estate) contained monthly records from 1977 to 2012 and 1977 to 1984, respectively. The remaining upstream monitoring points, including 188858 Illovo Sugar and 188865 Illovo Sugar discharge, were both sampled from 2005 to 2009. Monitoring stations (downstream) W4H007Q01 and W4H010Q01 were excluded as they contained very limited data (1984 to 1986). The remaining

monitoring points, i.e. W4H009Q01, W4R001Q01 1975-2008 and W4H013Q01 contained monthly data from 1977 to 2012, 1977 to 2008 and 1983 to 2012, respectively.

Additional samples were collected as part of this project at the selected sampling sites downstream of Pongolapoort Dam (Figure 2.2). Subsurface water samples were collected in pre-cleaned polypropylene containers (Sanders et al., 1983). *In situ* water quality parameters determined were dissolved oxygen (DO), total dissolved solids (TDS) and EC using a set of portable hand-held water quality meters. Other parameters analysed were alkalinity, total hardness (Ca and Mg) (assays performed by a SANAS-accredited laboratory). These data were used to determine the physicochemical driver assessment index (PAI).

3.2.2 Analytical methods

The water quality data comprising monthly records (1976-2012) were obtained from the DWA database. The impact of the dam and related agricultural activities were assessed by comparing the upstream historical water quality data (from monitoring points W4H003Q01, W4H006Q01, W4H011Q01, W4H008Q01, 188858 (Illovo Sugar) and 188865 (Illovo Sugar discharge) with the downstream monitoring points (W4H007Q01, W4H009Q01, W4R001Q01, W4H013Q01 and W4H010Q01) (Figure 3.1).

The available data for each parameter were averaged to annual records and then analysed statistically to determine water quality trends per site from 1976 to 2012. GraphPad Prism Software Version 5 was used to perform statistical analysis to determine the distribution of the data (box-and-whisker plots). Further statistical analyses included using the Mann-Kendall test (using XLSTAT) to identify significant water quality trends in the Phongolo River. The Mann-Kendall test is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values. The initial value of the Mann-Kendall statistic (*S*), is assumed to be 0 (e.g. no trend) if a data value from a later time period is higher than a data value from an earlier time period, *S* is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, *S* is decremented by 1. The net result of all such increments and decrements yields the final value of *S*. A very high positive value of *S* is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with *S* and the sample size, n, to statistically quantify the significance of the trend. The standardized *Z* test is approximately normally distributed. A positive (negative) value of *Z* indicate upwards (downward) trend. To test for the either upward or downward trend (a two-tailed test) at the alpha (α) level of significance, H_o is rejected if $|Z|>Z_{(1-\alpha/2)}$. Using the P-value calculated for *Z*, H_o is rejected if $P<\alpha$, where $\alpha = 0.05$.-2

3.2.3 Physicochemical driver assessment index (PAI)

The PAI, which forms part of the ecoclassification determination process, was applied to assess the PES of the water quality within the study area (Kleynhans et al., 2005). Different procedures are followed to assign an ecological category ranging from A to F, with A being natural and F meaning critically modified, to each component such as the PAI assessment (Table 3.1) (DWAF, 2008). The A to F scale used in the ecoclassification process represents a continuum where the boundaries between categories are imaginary defined points along the scale.

The PAI is a tool that is used to determine the present status of the physical and chemical water quality for a resource unit or a specific site. The PAI makes use of a Microsoft Excel based system for multi-criteria decision analysis that considers a range of water quality variables including pH, salts, nutrients, temperature, turbidity, dissolved oxygen and toxicants. The system makes use of a weighting and rating framework that allows for the assessment of individual variables, the integration of the variable outcomes and then the integrated, overall water quality state (Kleynhans et al., 2005).

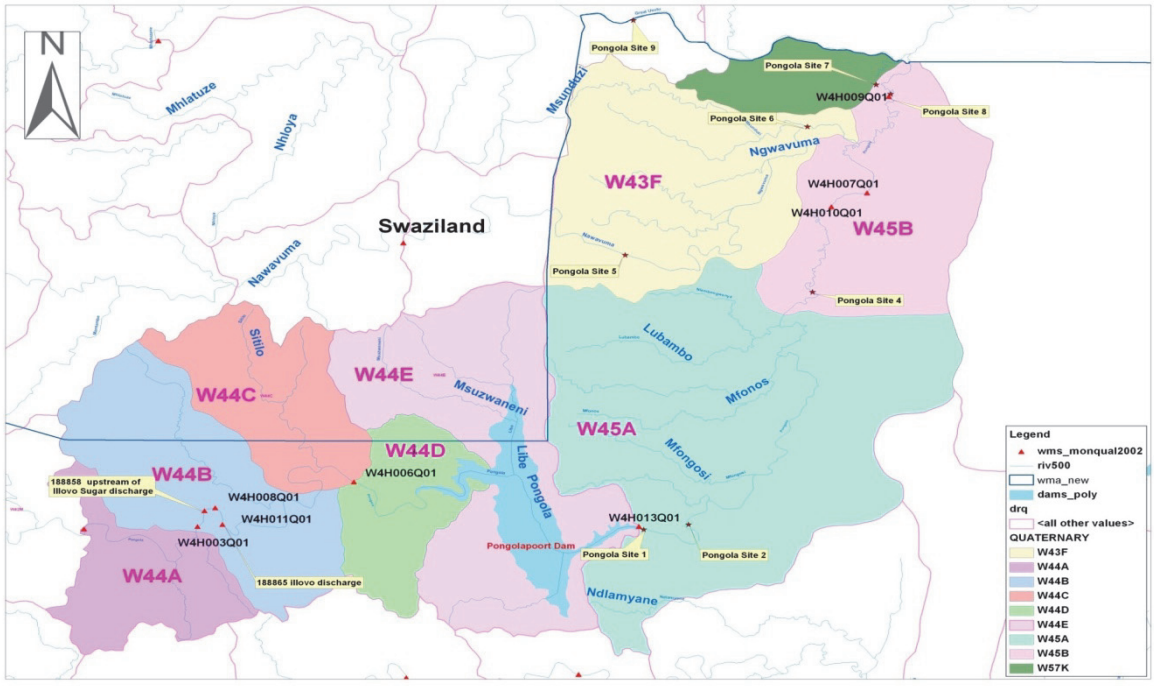


Figure 3.1. Position of the DWA monitoring sites in relation to the sampling sites selected for this study.

Table 3.1. Generic ecological categories for EcoStatus components (Kleynhans & Louw, 2008).

Ecological category	Description	Score (% of total)
A	**Unmodified**, natural.	90-100
B	**Largely natural** with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80-89
C	**Moderately modified.** Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	60-79
D	**Largely modified**. A large loss of natural habitat, biota and basic ecosystem functions has occurred	40-59
E	**Seriously modified.** The loss of natural habitat, biota and basic ecosystem functions is extensive.	20-39
F	**Critically / Extremely modified**. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19

3.3 Results

3.3.1 Middle Phongolo (upstream of the dam)

Station W4H003Q01

At this station, the pH of the available data ranged from 6.5 to 7.9 (data for the period of 1977 to 1995 obtained from DWA database). The mean of the annual average data was 7.403, which is within the target water quality guideline for aquatic ecosystems (DWAF, 1996) (Table 3.2). The mean concentrations of SO_4, NO_3/NO_2, PO_4 and NH_4 were 7.2, 0.144, 0.021, and 0.051 mg/l, respectively, during the study period. Calcium, Cl, K and Mg ranged from 5.4 to 12.6, 4.6 to 17.3, 0.7 to 2.1 and 2.9 to 8.7 mg/l, respectively. The EC ranged from 6.975 to 17.475 mS/m.-

Table 3.2. Descriptive water quality statistics at W4H003Q01 in the middle reaches of the Phongolo River. All concentrations are in mg/l, with the exception of EC which was measured in mS/m.

Station W4H003Q01												
	Ca	Cl	EC	F	K	Mg	Na	NH_4	NO_3/NO_2	pH	PO_4	SO_4
Mean	8.339	8.615	13.393	0.201	1.087	5.316	8.612	0.051	0.144	7.403	0.021	7.175
SD	±1.563	±3.114	±2.358	±0.048	±0.333	±1.101	±.796	±0.021	±0.068	±0.437	±0.009	±2.965
Max	12.600	17.300	17.479	0.298	2.137	8.700	13.100	0.110	0.266	7.978	0.040	12.495
Min	5.400	4.690	6.975	0.110	0.747	2.900	3.800	0.020	0.023	6.556	0.008	2.000

Station W4H006Q01

The mean pH of 8.166 was recorded at this station during the study period (Table 3.3). The mean concentrations of SO_4, NO_3/NO_2, PO_4 and NH_4 were 19.689, 0.568, 0.027, and 0.047 mg/l, respectively, during the study period. Calcium (Ca), Na and Mg ranged from 13.4 to 28.8, 35.5 to 144.9 and 12.57 to 42.6 mg/l, respectively. The EC ranged from 34 to 87 mS/m while the mean concentrations of Cl and Ca were 48.3 and 19.7 mg/l, respectively. Potassium, which potentially originates from fertilizers, ranged from 0.92 to 2.7 mg/l.

Table 3.3. Descriptive water quality statistics at W4H006Q01 in the middle reaches of the Phongolo River. All concentrations are in mg/l, with the exception of EC which was measured in mS/m.

Station W4H006Q01												
	Ca	Cl	EC	F	K	Mg	NO_3/NO_2	Na	PO_4	SO_4	pH	NH_4
Mean	19.720	48.319	56.154	0.411	1.503	22.052	0.568	72.733	0.027	19.689	8.166	0.047
SD	±3.945	±18.752	±15.033	±0.122	±0.449	±7.386	±0.245	±28.910	±0.017	±6.291	±0.338	±0.026
Max	28.767	99.400	87.325	0.705	2.864	42.578	1.093	144.943	0.082	35.252	8.595	0.133
Min	13.390	20.757	34.005	0.235	0.927	12.574	0.133	35.525	0.006	7.535	7.436	0.020

Station W4H011Q01

The pH ranged from 6.8 to 7.7 with a mean of 7.4 and was found to be well within the target water quality guideline for aquatic ecosystem (DWAF, 1996) (Table 3.4). The mean concentrations of SO_4, NO_3/NO_2, PO_4 and NH_4 were 13.670, 0.311, 0.025 and 0.052 mg/l, respectively, during the study period. Calcium (Ca), K, Na, Cl and Mg ranged from 8.9 to 17.9, 0.69 to 1.7, 11.7, 11.2 to 52.8 and 6.4 to 20.4 mg/l, respectively. The EC was found to be within the required range for the protection of the aquatic life with a mean of 32.7 mS/m. The PO_4 concentration was higher than the target water quality range of 0.005 mg/l.

Station 188858 Illovo Sugar

The highest pH measured during the study period was 8.4 while the lowest was 7.7 with a mean of 7.9 (Table 3.5). The mean concentration NO_3/NO_2 and NH_4 were 0.78 and 0.13 mg/l, respectively, during the study period. Data for SO_4 and PO_4 were not available. Calcium, K, Na, Cl and Mg ranged from 6.9 to 14.8, 0.61 to 16.5, 17.3 to 47.5, 13.8 to 38.6 and 6.3to 16.5 mg/l, respectively. The electrical conductivity (EC) ranged from 18 to 213.5 mS/m with the mean of 68.8 mS/m while the mean concentration of Cl was 22.9 mg/l during the study period.

Table 3.4. Descriptive water quality statistics at W4H011Q01 in the middle reaches of the Phongolo River. All concentrations are in mg/l, with the exception of EC, which was measured in mS/m.

Station W4H011Q01											
	Ca	Cl	EC	K	Mg	NO_3/NO_2	Na	PO_4	SO_4	pH	NH_4
Mean	13.712	28.382	32.735	1.155	13.227	0.311	33.243	0.025	13.670	7.440	0.052
SD	±3.339	±17.689	±14.313	±0.377	±5.762	±0.133	±20.886	±0.013	±5.283	±0.426	±0.023
Max	17.927	52.841	50.277	1.735	20.391	0.494	59.436	0.040	21.067	7.869	0.074
Min	8.922	11.200	16.367	0.690	6.378	0.151	11.711	0.003	6.256	6.856	0.020

Table 3.5. Descriptive water quality statistics at 188858 Illovo Sugar in the middle reaches of the Phongolo River. All concentrations are in mg/l, with the exception of EC which was measured in mS/m.

Station 188858 Illovo Sugar										
	Ca	Cl	EC	F	K	Mg	Na	NH_4	NO_3/NO_2	pH
Mean	12.022	22.589	68.833	0.440	1.003	12.793	35.078	0.129	0.708	7.953
SD	±3.097	±9.506	±81.359	±0.070	±0.471	±4.044	±11.410	±0.078	±0.132	±0.267
Max	14.838	38.583	213.500	0.533	1.775	16.488	47.500	0.219	0.855	8.383
Min	6.875	13.750	18.000	0.353	0.613	6.250	17.250	0.053	0.549	7.675

Station 188865 Illovo Sugar discharge

At this station, the pH ranged from 7.8 to 8.3 with a mean of 8.0, which is within the target water quality guideline for aquatic ecosystems (DWAF, 1996) (Table 3.6). The mean concentrations of NO_3/NO_2 and NH_4 were 0.66 and 0.15 mg/l, respectively, during the study period. Data for SO_4 and PO_4 were not available. Calcium (Ca), Na, Cl and Mg ranged from 7.1 to 16.4, 18.5 to 51.9, 12.7 to 42 and 6.4 to 17.1 mg/l, respectively. Chloride concentrations ranged from 12.7 to 42 while K ranged from 0.8 to 2.7 mg/l. The maximum EC was 225 mS/m.

These upstream sites indicated signs of pollution especially at the Illovo Sugar monitoring points where the EC values were as high as 225 mS/m at the Illovo Sugar discharge point as reflected in the K and Cl concentrations. The nutrient levels (PO_4, NH_4, and NO_3/NO_2) were also elevated.

Table 3.6. Descriptive water quality statistics at 188865 Illovo Sugar discharge point in the middle reaches of the Phongolo River. All concentrations are in mg/l, with the exception of EC which was measured in mS/m.

Station 188865 Illovo Sugar discharge point									
	Ca	Cl	EC	K	Mg	Na	NH_4	NO_3/NO_2	pH
Mean	12.872	21.827	72.833	1.657	12.816	35.830	0.150	0.662	8.029
SD	±3.813	±11.796	±85.664	±0.840	±4.479	±13.263	±0.108	±0.166	±0.237
Max	16.392	42.000	225.000	2.692	17.133	51.917	0.323	0.838	8.300
Min	7.050	12.708	18.500	0.800	6.400	18.500	0.050	0.483	7.750

3.3.2 Phongolo River (downstream of the dam)

Station W4H008Q01

The high pH ranging from 7.6 to 8.6 with a mean of 8.0 was recorded at this station located downstream of the dam (Table 3.7). The mean concentrations of SO_4, NO_3/NO_2, PO_4 and NH_4 were 31, 1.1, 0.03 and 0.03 mg/l, respectively, during the study period. Calcium, K, Cl, Na and Mg ranged from 27.3 to 63.7, 2.1 to 5.5, 124.2 to 284.6, 148 to 286.3 and 24.2 to 50.4 mg/l, respectively. The EC ranged from 47.1 to 193 mS/m during the study period.

Table 3.7. Descriptive water quality statistics at Station W4H008Q01 in the Phongolo River below the dam. All concentrations are in mg/l, with the exception of EC which was measured in mS/m.

Station W4H008Q01												
	Ca	Cl	EC	F	K	Mg	NO_3/NO_2	Na	PO_4	SO_4	pH	NH_4
Mean	10.231	47.707	42.373	0.110	1.147	7.583	1.082	42.606	0.026	31.030	8.015	0.029
SD	±10.231	±47.707	±42.373	±0.110	±1.147	±7.583	±1.082	±42.606	±0.026	±31.030	±0.308	±0.029
Max	63.700	284.600	193.000	0.700	5.520	50.400	3.498	286.300	0.107	152.300	8.590	0.106
Min	27.329	124.250	47.100	0.405	2.139	24.233	0.687	148.046	0.031	43.333	7.588	0.022

Station W4H009Q01

At this station, the pH ranged from 6.9 to 8.6 with a mean of 7.9 (Table 3.8). The mean concentrations of SO_4, NO_3/NO_2, PO_4 and NH_4 were 21.3, 0.243, 0.04 and 0.05 mg/l, respectively, during the study period. Calcium, K, Na, Cl and Mg ranged from 11.6 to 48.7, 1.4 to 4.030, 31.9 to 112.4, 33. to 135.5 and 8.9 to 27.5 mg/l, respectively. The mean EC ranged from 33.5 to 78.1 mS/m with a mean of 48.6 mS/m.

Table 3.8. Descriptive water quality statistics at Station W4H0098Q01 in the Phongolo River below the dam. All concentrations are in mg/l, with the exception of EC, which was measured in mS/m.

Station W4H009Q01												
	Ca	Cl	EC	F	K	Mg	NO_3/NO_2	Na	PO_4	SO_4	pH	NH_4
Mean	21.942	65.030	48.599	0.350	2.462	15.244	0.243	52.113	0.036	21.295	7.959	0.048
SD	±5.953	±22.719	±10.827	±0.089	±0.557	±3.658	±0.182	±16.563	±0.048	±16.508	±0.369	±0.028
Max	48.704	135.500	78.100	0.600	4.030	27.450	0.782	112.400	0.287	102.191	8.591	0.155
Min	11.600	33.500	33.200	0.230	1.400	8.900	0.020	31.900	0.003	7.200	6.880	0.020

Station W4R001Q01

At this station, the pH ranged from 7.1 to 8.3 with a mean of 7.9, which is within the target water quality guideline for aquatic ecosystem (DWAF, 1996) (Table 3.9). The mean concentrations of SO_4, NO_3/NO_2, PO_4 and NH_4 were 12.6, 0.25, 0.024 and 0.042 mg/l, respectively, during the study period. Calcium, K, Cl, Na and Mg ranged from 9.3 to 33.1, 0.57 to 3.01, 12.9 to 165.4, 14.4 to 121.1 and 7.25 to 31.1 mg/l, respectively. The EC was very low with a mean value of 33.4 mS/m.

Table 3.9. Descriptive water quality statistics at Station W4R001Q01 in the Phongolo River below the dam. All concentrations are in mg/l, with the exception of EC, which was measured in mS/m.

Station W4R001Q01											
	Ca	Cl	EC	K	Mg	NO_3/NO_2	Na	PO_4	SO_4	pH	NH_4
Mean	15.629	30.935	33.446	1.817	11.293	0.247	33.498	0.024	12.571	7.937	0.042
SD	±4.714	±33.383	±16.254	±0.404	±5.229	±0.220	±22.934	±0.024	±4.455	±0.372	±0.021
Max	33.050	165.430	96.267	3.008	31.117	1.122	121.080	0.117	25.667	8.304	0.095
Min	9.300	12.970	19.925	0.570	7.250	0.005	14.425	0.006	6.332	7.125	0.017

Station W4H013Q01

The pH ranged from 7.2 to 8.3 with a mean of 7.9 (Table 3.10). The mean concentrations of SO_4, NO_3/NO_2, PO_4 and NH_4 were 14.6, 0.23, 0.02 and 0.05 mg/l, respectively, during the study period. Calcium, K, Na and Mg ranged from 12.6 to 17.6, 1.6 to 3, 15.7 to 35.2 and 8.1 to 13.2 mg/l, respectively. The EC ranged from 22.7 to 36.7 mS/m and the Cl ranged from 13.2 to 27.7 mg/l.

Table 3.10. Descriptive water quality statistics at Station W4H013Q01 in the Phongolo River below the dam. All concentrations are in mg/l, with the exception of EC, which was measured in mS/m.

Station W4H013Q01												
	Ca	Cl	EC	F	K	Mg	Na	NH_4	NO_3/NO_2	pH	PO_4	SO_4
Mean	15.130	22.006	29.795	0.299	1.917	10.303	27.151	0.054	0.229	7.992	0.016	14.635
SD	±1.421	±4.278	±3.700	±0.087	±0.354	±1.515	±4.834	±0.052	±0.141	±0.305	±0.007	±9.623
Max	17.579	27.681	36.713	0.648	3.020	13.151	35.167	0.270	0.680	8.288	0.037	56.200
Min	12.640	13.171	22.700	0.220	1.590	8.100	15.700	0.024	0.043	7.170	0.006	6.450

The sites downstream of Pongolapoort Dam generally had lower EC values than those above the dam. However, levels of PO_4, K and Cl were higher.

3.3.3 Water quality trends

The analysis of historical water quality data (1970s-1990s) indicated that both the upstream and downstream water quality monitoring stations indicated exceedingly high levels of PO_4, NO_3/NO_2, NH_4, K, pH and EC. These parameters were therefore selected for the purpose of trend analysis to determine whether these levels were increasing or decreasing over the study period. These water quality parameters serve as indicators for agricultural related land-use activities that are dominating the catchment, due to irrigation water provided by the Pongolapoort Dam.

Upstream of Pongolapoort Dam

Station W4H003Q01

An increasing trend was detected for the pH and PO_4 at this station where the computed p-values (0.008 and 0.003) were found to be lower than $\alpha = 0.05$ and the slope (change per unit) was 8.4 for PO_4 while for pH it was 0.05 (Table 3.11). Other variables including NO_3/NO_2, NH_4, K and EC did not reveal any trend. A visual inspection of the time series plots for these parameters indicated that an upward trend of NO_3/NO_2 and K may exist (Figures 3.2 and 3.3).

Table 3.11. Significance testing of the trends in water quality parameters at Station W4H003Q01 between 1977 and 1995.

	Statistical results		Mann-Kendall trend test/two-tailed test						
Station ID	Variable	Std. deviation	Kendall's tau	S	Var (S)	p-value (Two-tailed)	Alpha	Slope	Interpretation
W4H003Q01	PO_4	0.009	0.439	75.000	0.000	0.008	0.05	8.442	Reject H_0
	NO_3/NO_2	0.068	0.287	49.000	0.000	0.093	0.05	0.006	Fail to reject H_0
	NH_4	0.021	-0.088	0.000	0.000	0.629	0.05	0.629	Fail to reject H_0
	K	0.333	0.298	51.000	0.000	0.080	0.05	0.017	Fail to reject H_0
	EC	2.358	-0.088	-15.000	0.000	0.629	0.05	-0.033	Fail to reject H_0
	pH	0.437	0.485	83.000	0.000	0.003	0.05	0.049	Reject H_0

Station W4H006Q01

An increasing trend was detected for the pH, PO_4, K and NH_4 where the computed p-values (0.0003, 0.042, 0.021 and 0.002) were found to be lower than $\alpha = 0.05$ (Table 3.12). Visual inspections of the time series plots indicated the downward trend of EC and NO_3/NO_2 which indicates that a stable condition may exist (Figures 3.4 and 3.5).

Table 3.12. Significance testing of the trends in water quality parameters at Station W4H006Q01 between 1976 and 2012.

Station ID	Statistical results		Mann-Kendall trend test/two-tailed test						Interpretation
	Variable	Std. deviation	Kendall's tau	S	Var (S)	p-value (Two-tailed)	Alpha (α)	Slope	
W4H006Q01	PO_4	0.017	0.238	150.000	0.000	0.042	0.05	3.582	Reject H_0
	NO_3/NO_2	0.245	0.035	22.000	0.000	0.777	0.05	0.002	Fail to reject H_0
	NH_4	0.026	-0.272	-171.000	5386.333	0.021	0.05	-6.576	Reject H_0
	K	0.449	0.362	228.000	0.000	0.002	0.05	0.018	Reject H_0
	EC	15.033	-0.219	-138.000	0.000	0.062	0.05	-0.474	Fail to reject H_0
	pH	0.338	0.410	258.000	0.000	0.0003	0.05	0.017	Reject H_0

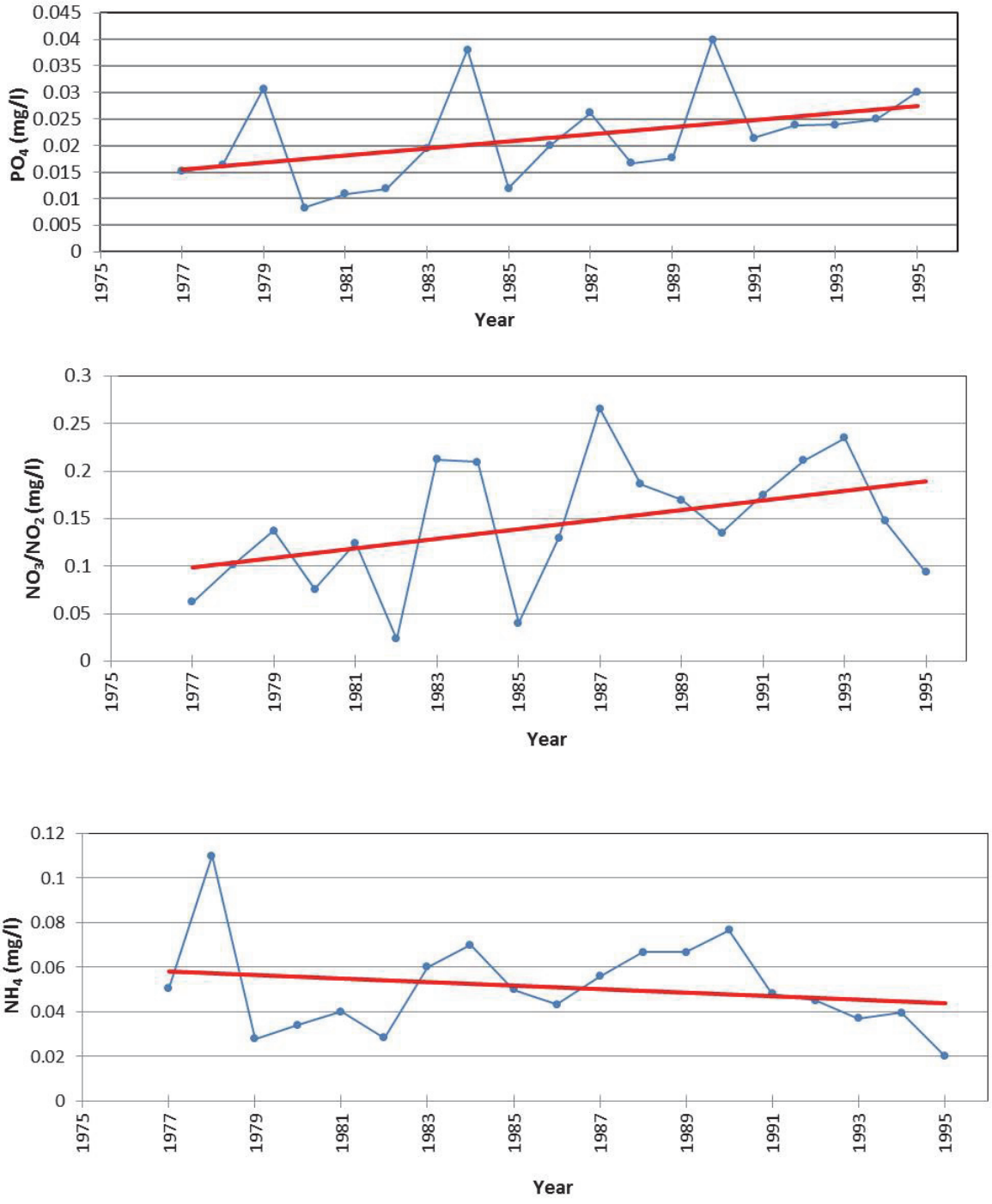
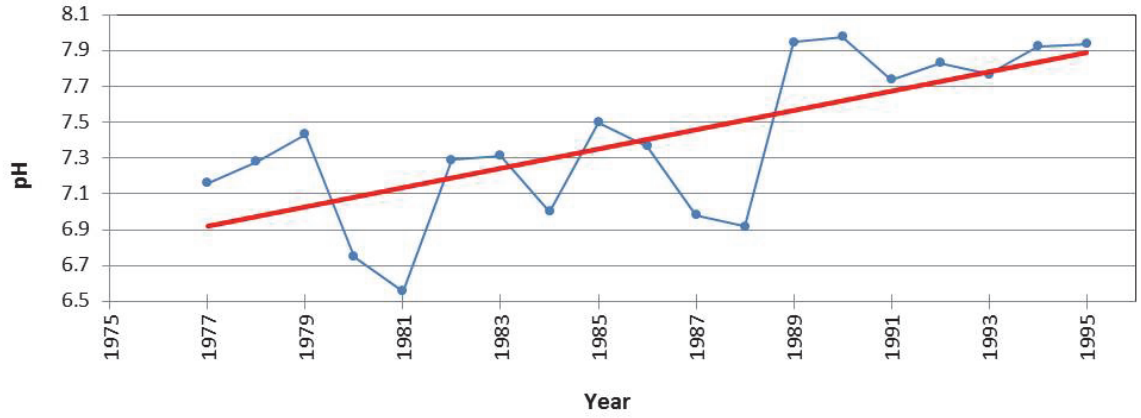
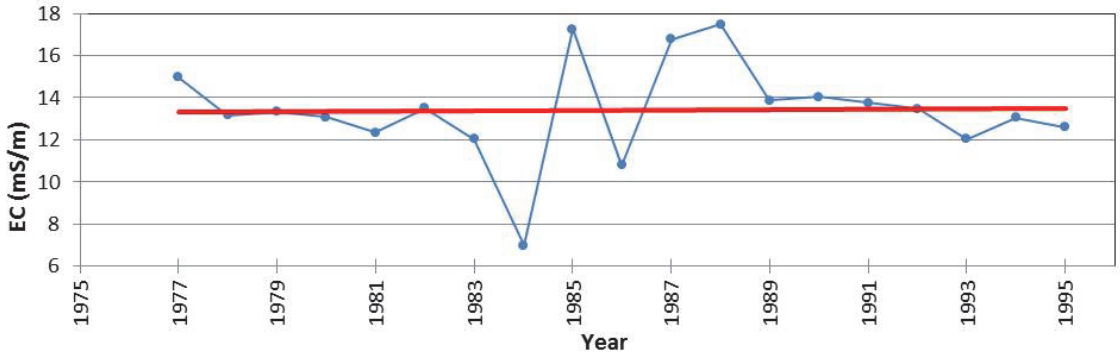


Figure 3.2. Trends in nutrient concentrations at Station W4H003Q01 between 1977 and 1995.





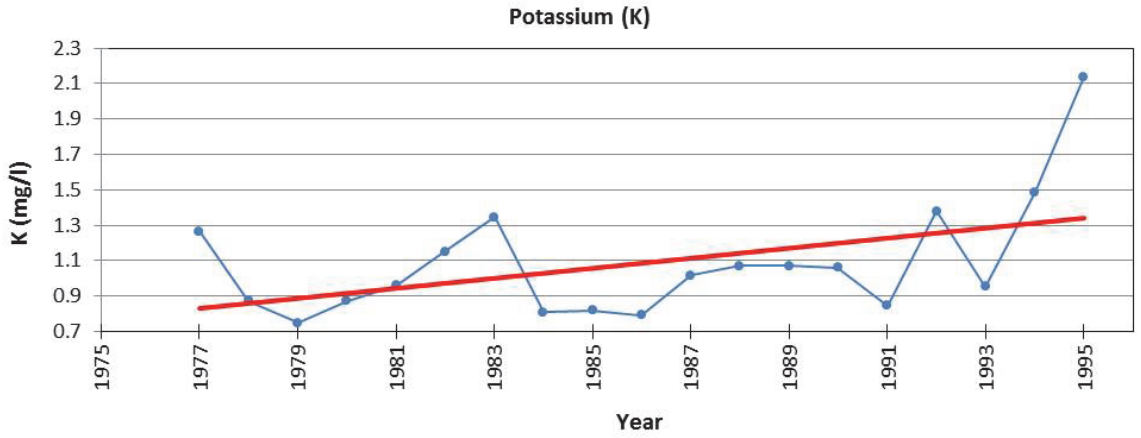
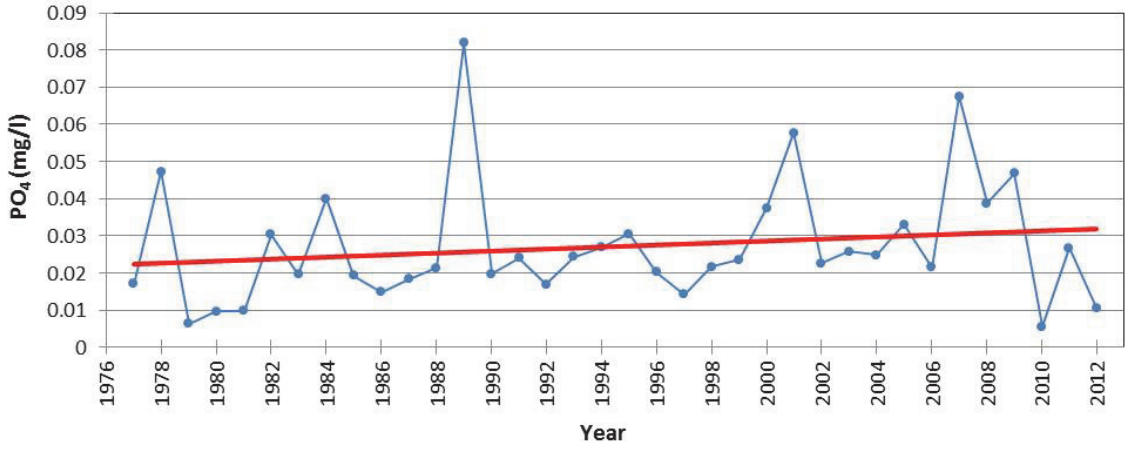
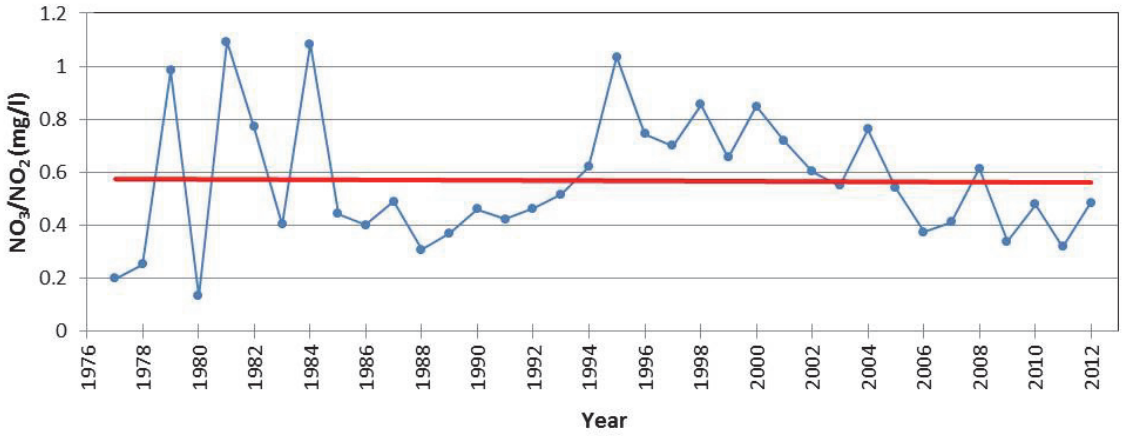


Figure 3.3. Trends in pH, electrical conductivity and K concentrations at Station W4H003Q01 between 1977 and 1995.





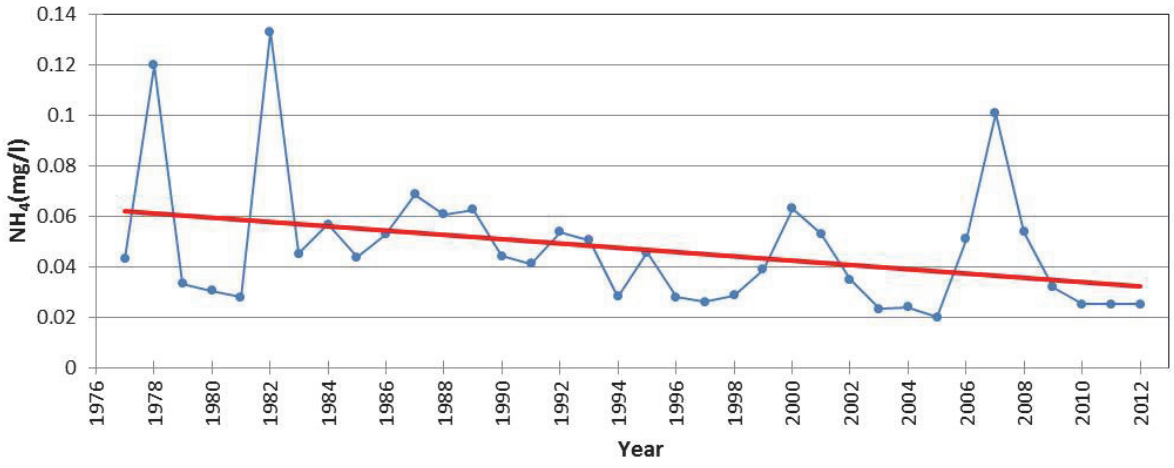


Figure 3.4. Trends in nutrient concentrations at Station W4H006Q01 between 1976 and 2012.

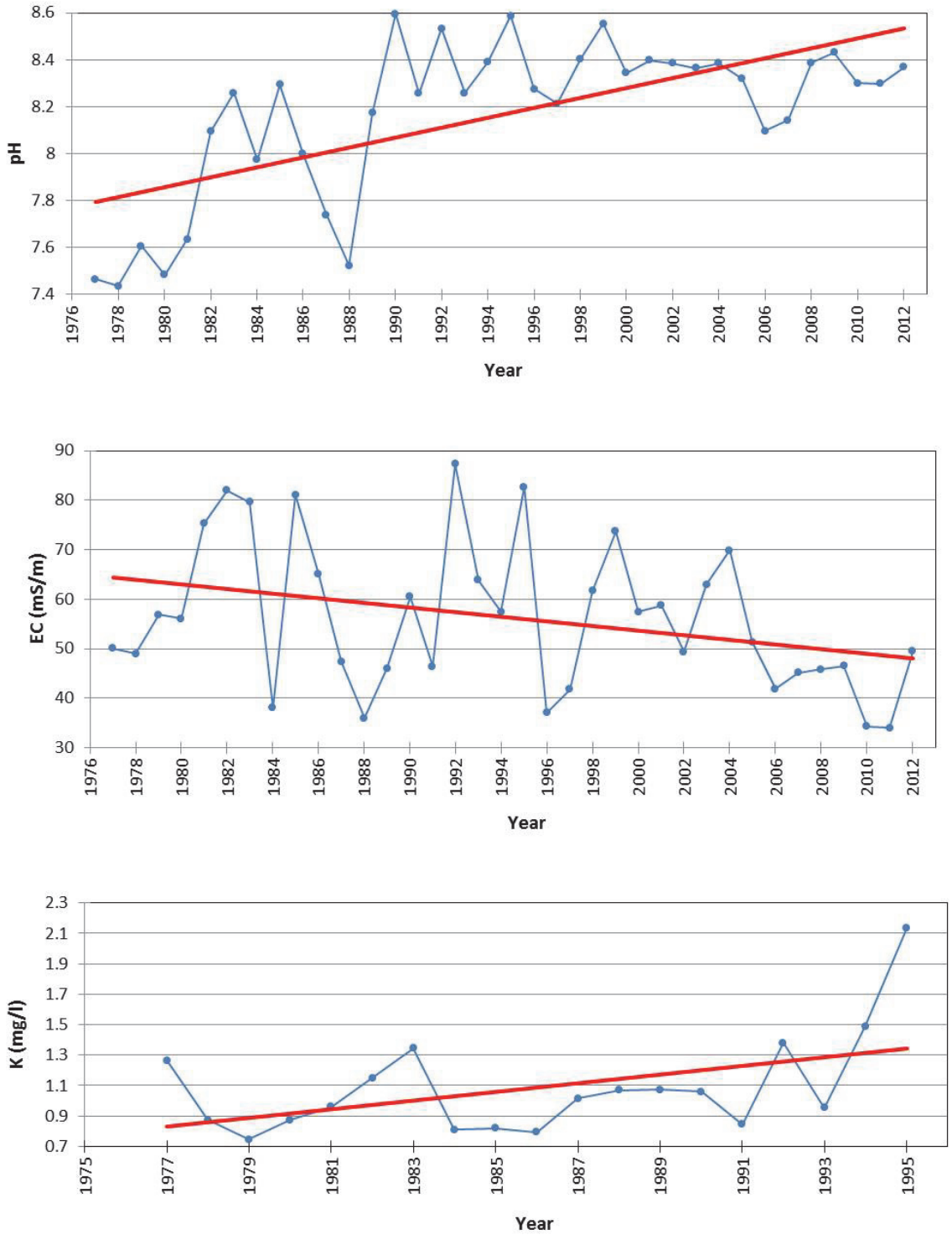


Figure 3.5. Trends in pH, electrical conductivity and K concentrations at Station W4H006Q01 between 1976 and 2012.

Station W4H011Q01

All water quality parameters results indicate a stable trend since the computed p-values are greater than α = 0.05 (Table 3.13). Visual inspections of the time series plots indicated that an upward trend of pH, PO_4 and NH_4 may exist, while NO_3/NO_2, EC and K trends were stable (Figures 3.14 to 3.19).

Table 3.13. Significance testing of the trends in water quality parameters at Station W4H011Q01 between 1984 and 1988.

Station ID	Statistical results		Mann-Kendall trend test/two-tailed test						Interpretation
	Variable	Std. deviation	Kendall's tau	S	Var (S)	p-value (Two-tailed)	Alpha	Slope	
W4H011Q01	PO_4	0.013	0.200	2.000	0.000	0.817	0.05	0.001	Fail to reject H_0
	NO_3/NO_2	0.133	0.200	2.000	0.000	0.817	0.05	0.063	Fail to reject H_0
	NH_4	0.023	0.800	8.000	0.000	0.083	0.05	0.016	Fail to reject H_0
	K	0.377	0.000	0.000	0.000	0.817	0.05	0.034	Fail to reject H_0
	EC	14.313	0.000	0.000	0.000	0.817	0.05	0.529	Fail to reject H_0
	pH	0.023	0.800	8.000	0.000	0.083	0.05	0.016	Fail to reject H_0

Station W4H008Q01

No trends were detected in any of the variables tested since the computed p-value is greater than the significance level (Table 3.14). Visual inspections of the time series plots indicated the upward trends of NH_4, K, pH NO_3/NO_4 and EC whereas PO_4 shows a downward trend at a slope of 0.002 (Figures 3.8 and 3.9).

Table 3.14. Significance testing of the trends in water quality parameters at Station W4H008Q01 between 1977 and 1984.

Station ID	Statistical results		Mann-Kendall trend test/two-tailed test						Interpretation
	Variable	Std. deviation	Kendall's tau	S	Var (S)	p-value (Two-tailed)	Alpha	Slope	
W4H008Q01	PO_4	0.026	0.143	4.000	0.000	0.720	0.05	0.002	Fail to reject H_0
	NO_3/NO_2	1.082	0.429	12.000	0.000	0.179	0.05	0.338	Fail to reject H_0
	NH_4	0.029	0.071	2.000	0.000	0.905	0.05	0.002	Fail to reject H_0
	K	1.147	0.50	14.000	0.000	0.108	0.05	0.272	Fail to reject H_0
	EC	28.344	0.143	4.000	0.000	0.719	0.05	6.865	Fail to reject H_0
	pH	0.308	0.571	16.000	0.000	0.061	0.05	0.092	Fail to reject H_0

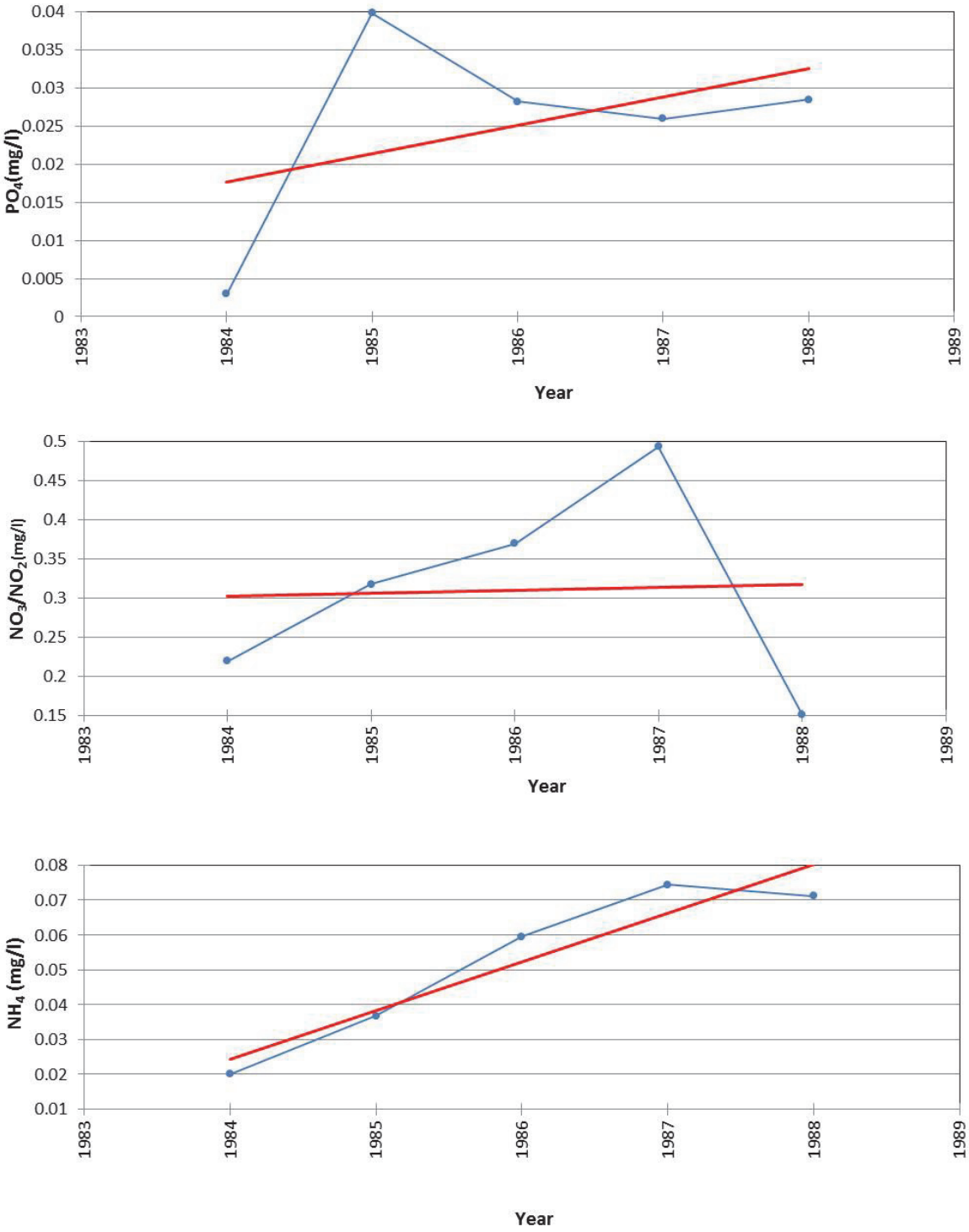


Figure 3.6. Trends in nutrient concentrations at Station W4H011Q01 between 1984 and 1988.

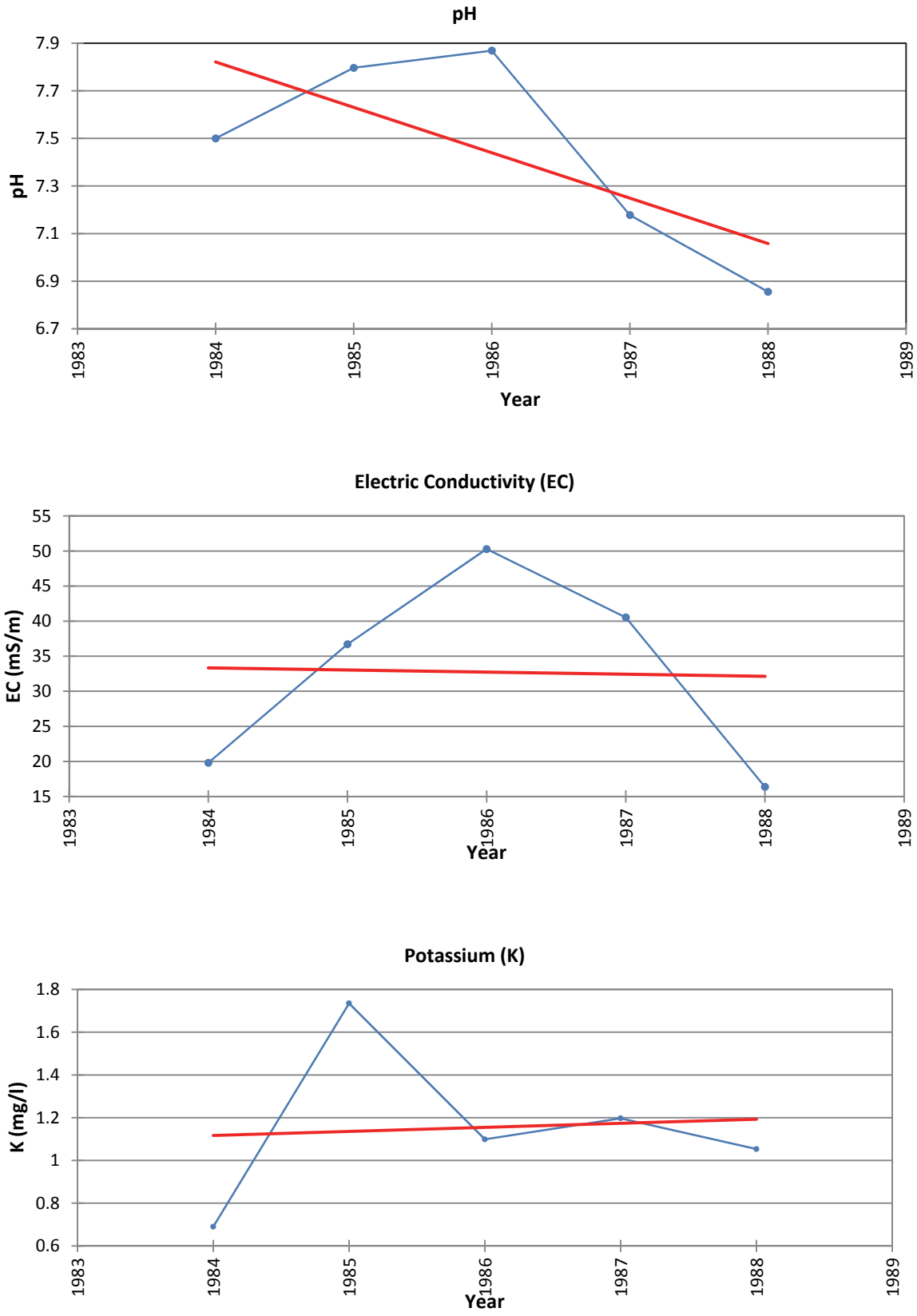


Figure 3.7. Trends in pH, electrical conductivity and K concentrations at Station W4H011Q01 between 1984 and 1988.

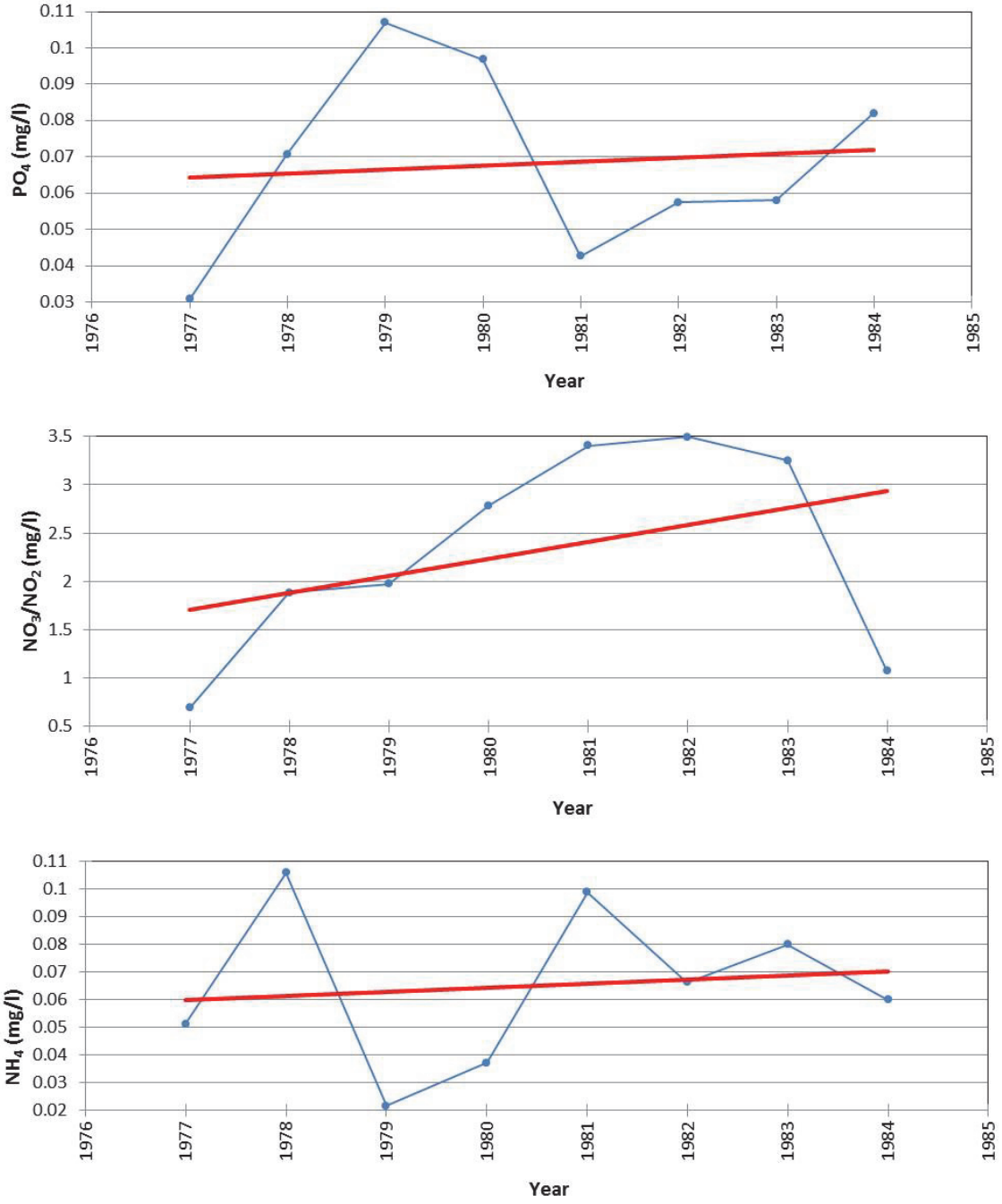


Figure 3.8. Trends in nutrient concentrations at Station W4H008Q01 between 1977 and 1984.

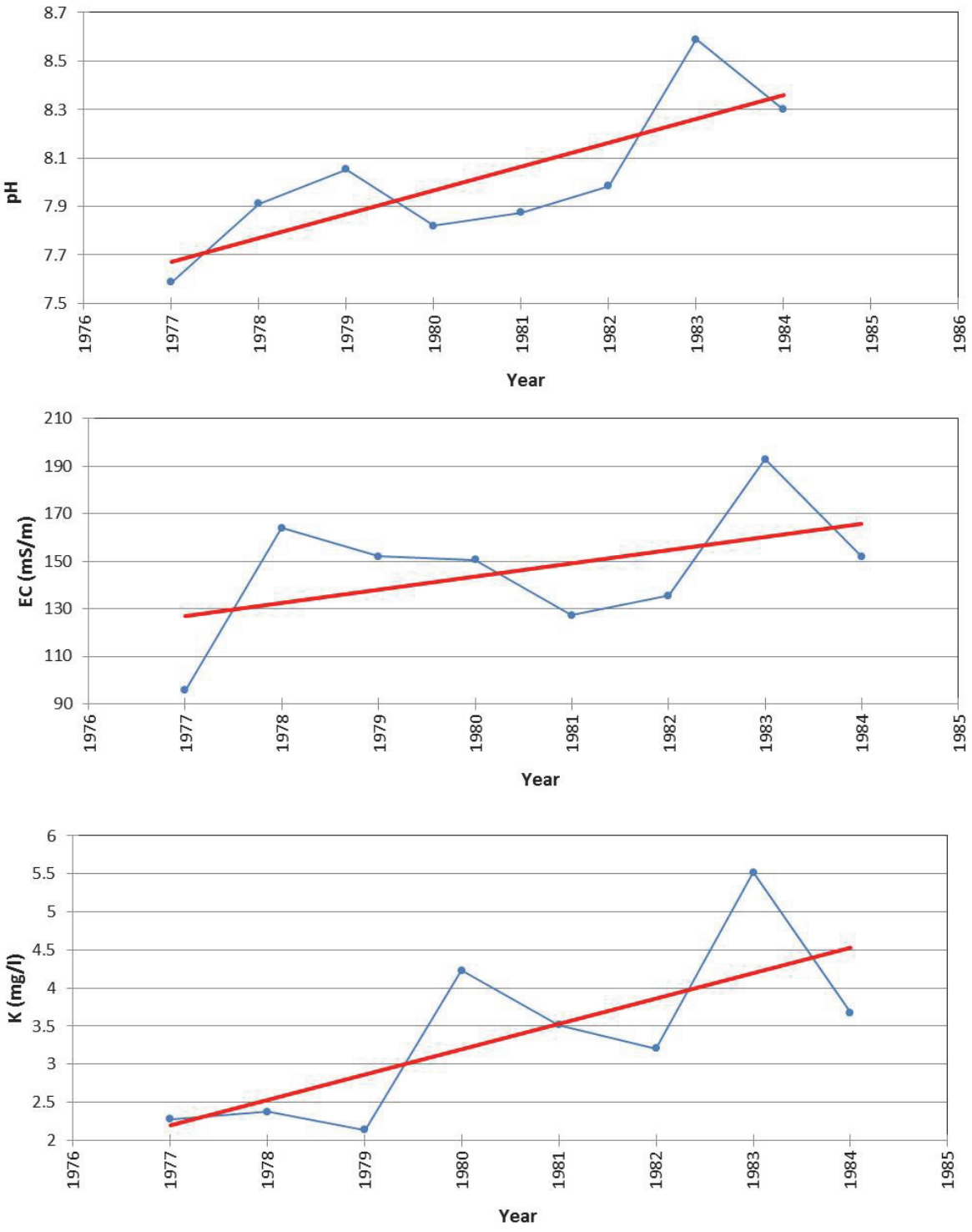


Figure 3.9. Trends in pH, electrical conductivity and K concentrations at Station W4H008Q01 between 1977 and 1984.

Station 188858 Illovo Sugar

No trend was detected in any of the variables tested since the computed p-value was greater than the significance level (Table 3.15) although the data were limited (2005-2009). Visual inspections of the time series plots indicated the upward trend of pH, NH_4, NO_3/NO_4 and K whereas the EC shows a downward trend (Figures 3.10 and 3.11).

Table 3.15. Significance testing of the trends in water quality parameters at Station 188858 Illovo sugar between 2005 and 2009.

Station ID	Statistical results		Mann-Kendall trend test/two-tailed test						Interpretation
	Variable	Std. deviation	Kendall's tau	S	Var (S)	p-value (Two-tailed)	Alpha	Slope	
188858 Illovo	NO_3/NO_2	0.132	0.400	4.000	0.000	0.483	0.05	0.054	Fail to reject H_0
	NH_4	0.078	0.400	4.000	0.000	0.483	0.05	0.031	Fail to reject H_0
	K	0.471	0.400	4.000	0.000	0.483	0.05	0.192	Fail to reject H_0
	EC	81.359	-0.600	-6.000	0.000	0.233	0.05	-15.834	Fail to reject H_0
	pH	0.267	0	0	0.000	0.817	0.05	0.01	Fail to reject H_0

Station 188865 Illovo discharge

No trend was detected in any of the variables tested since the computed p-value is greater than the significance level (Table 3.16). Visual inspections of the time series plots indicated upward trends of pH, NH_4, NO_3/NO_4 and K whereas EC shows a downward trend (Figures 3.12 and 3.13).

The trend analysis indicated that the upstream catchments of the Pongolapoort Dam are experiencing major disturbance mostly relating to sugarcane production. This is evident from the increasing trends of pH, PO_4, K, NH_4 and EC across the upstream monitoring stations. These parameters are all closely linked to agricultural practices.

Table 3.16. Significance testing of the trends in water quality parameters at Station 188865 Illovo Sugar discharge between 2005 and 2009.

Station ID	Statistical results		Mann-Kendall trend test/two-tailed test						Interpretation
	Variable	Std. deviation	Kendall's tau	S	Var (S)	p-value (Two-tailed)	alpha	Slope	
188865 Illovo discharge	NO_3/NO_2	0.166	0.400	4.000	0.000	0.483	0.05	0.053	Fail to reject H_0
	NH_4	0.108	0.400	4.000	0.000	0.483	0.05	0.062	Fail to reject H_0
	K	0.840	0.000	0.000	0.000	0.817	0.05	-0.006	Fail to reject H_0
	EC	85.664	-0.600	-6.000	0.000	0.233	0.05	-18.354	Fail to reject H_0
	pH	0.237	-0.470	-4.000	0.000	0.483	0.05	-0.084	Fail to reject H_0

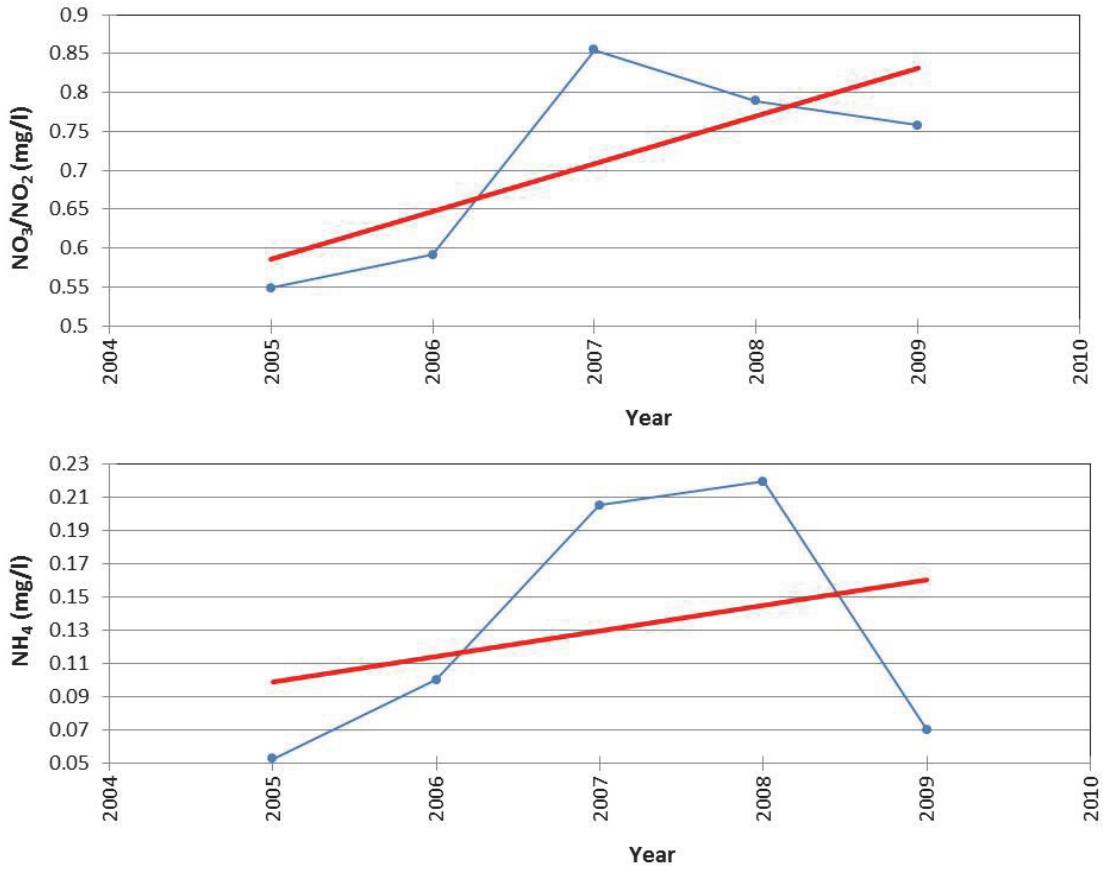


Figure 3.10. Trends in nutrient concentrations at Station 188858 Illovo Sugar between 2005 and 2009. Note that no PO_4 data were available.

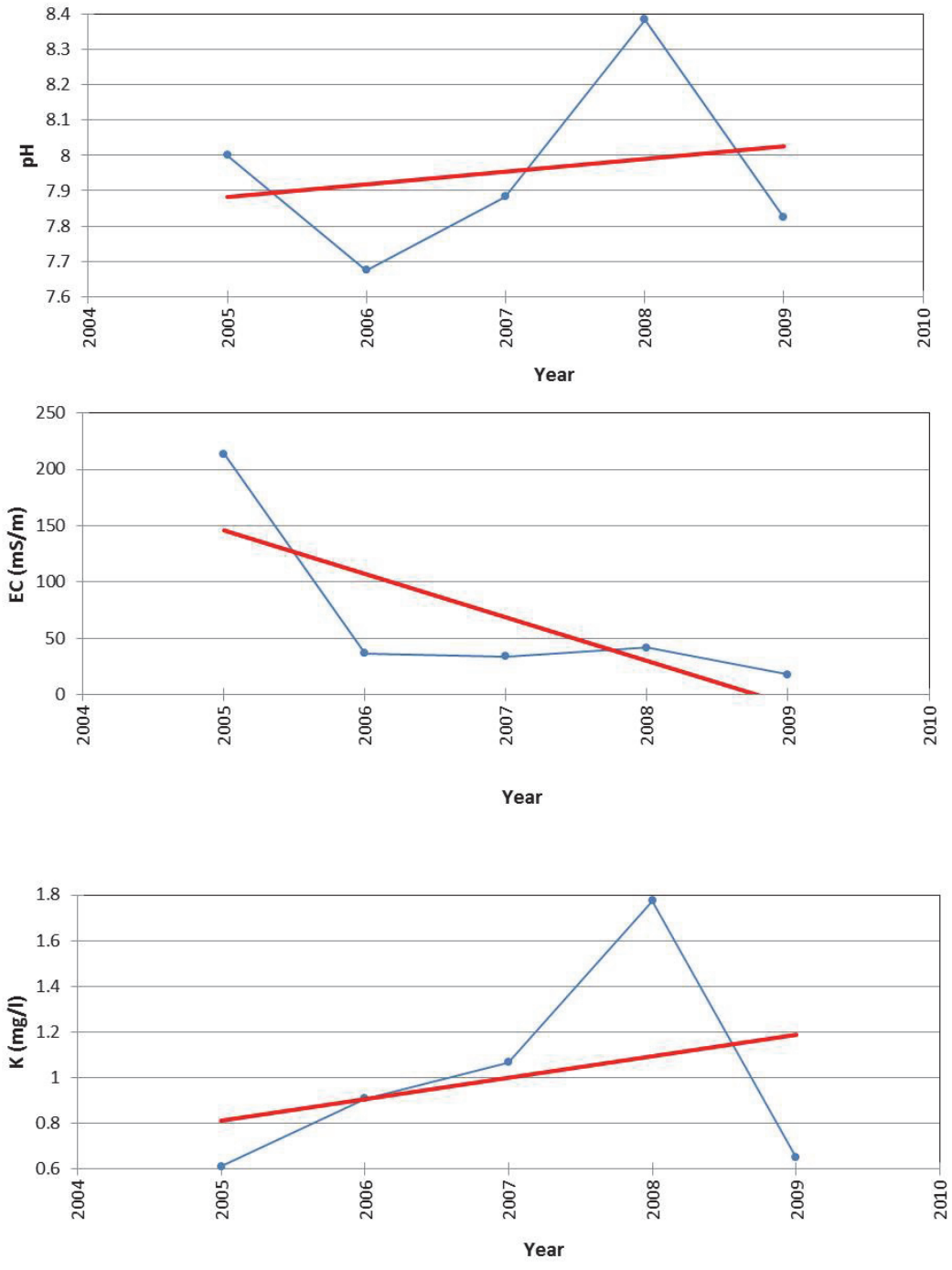


Figure 3.11. Trends in pH, electrical conductivity and K concentrations at Station 188858 Illovo Sugar between 2005 and 2009.

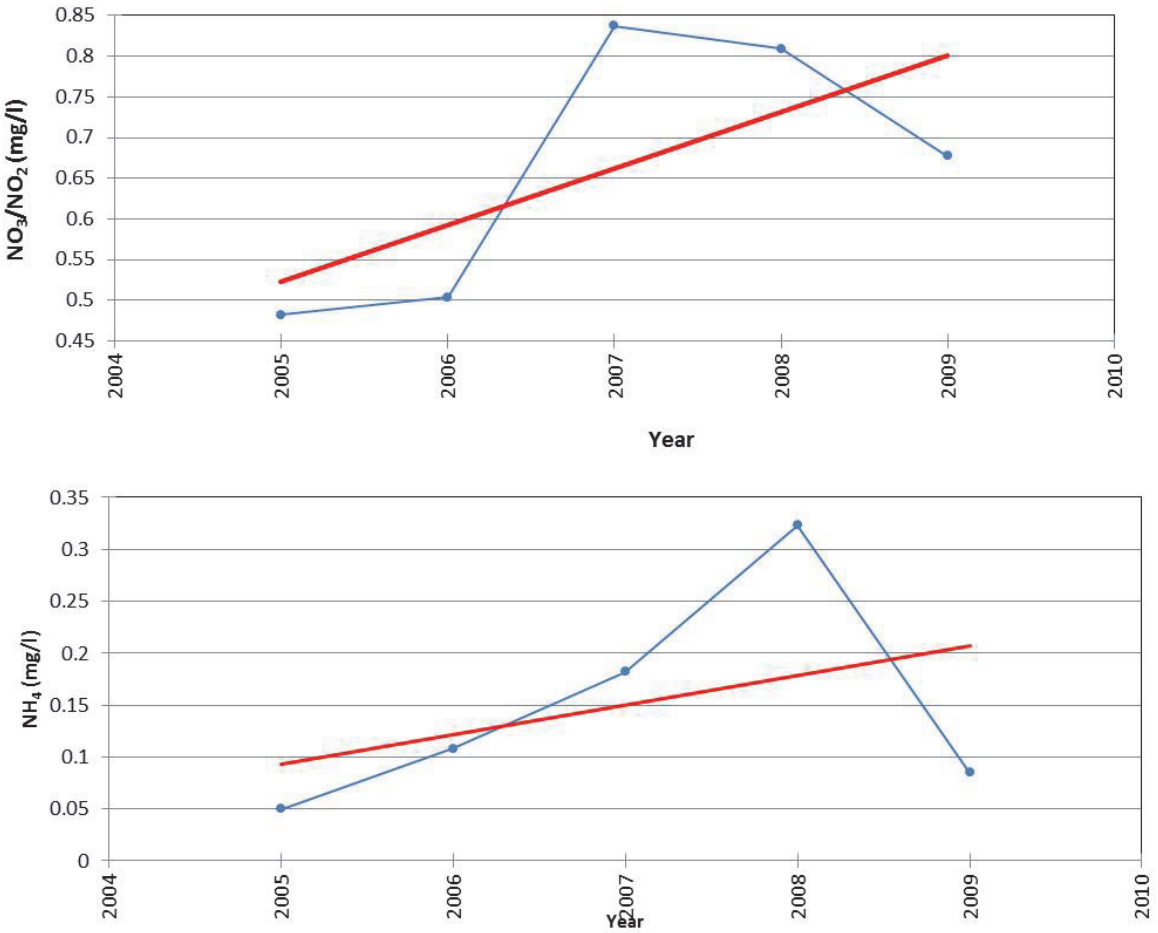


Figure 3.12. Trends in nutrient concentrations at Station 188865 Illovo Sugar discharge between 2005 and 2009. Note that no PO_4 data were available.

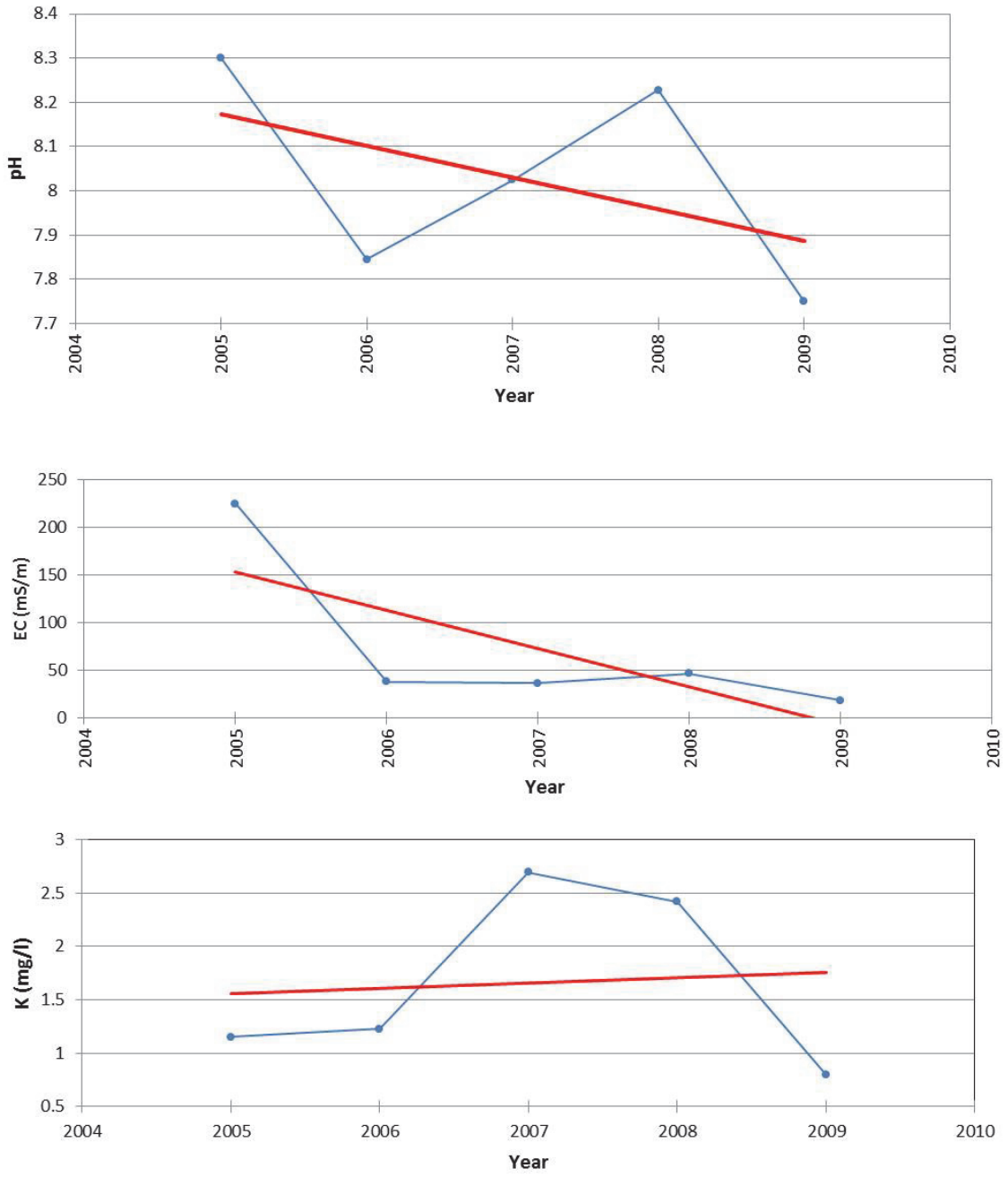


Figure 3.13. Trends in pH, electrical conductivity and K concentrations at Station 188865 Illovo Sugar discharge between 2005 and 2009.

Lower Phongolo River

Station W4H009Q01

A trend was detected for the pH, NO_3/NO_2 and EC where the computed p-value (0.002 and 0.014) was found to be lower than the significance value (Table 3.17). The graphic plots indicated an increasing trend for EC and decreasing trend for NO_3/NO_2 (Figures 3.14 and 3.15). No trends were detected in any of the other variables tested indicating that the water quality in the area is stable.

Station W4R001Q01

A trend was detected for the NO_3/NO_2, K and EC where the computed p-value (0.0002, 0.011 and 0.018) was found to be lower than the significance value alpha ($\alpha = 0.05$) (Table 3.18). The graph shows the increasing trend for K and decreasing trend for NO_3/NO_2 and EC (Figures 3.16 and 3.17). No trends were detected in other variables tested indicating that the water quality in the area is stable.

Table 3.17. Significance testing of the trends in water quality parameters at Station W4H009Q01 between 1980 and 2012.

Station ID	Statistical results		Mann-Kendall trend test/two-tailed test						Interpretation
	Variable	Std. deviation	Kendall's tau	S	Var (S)	p-value (Two-tailed)	alpha	Slope	
W4H009Q01	PO_4	0.049	0.205	108	0	0.098	0.05	3.371	Fail to reject H_0
	NO_3/NO_2	0.182	-0.375	-198	0	0.002	0.05	-0.008	Reject H_0
	NH_4	0.028	-0.154	-81.	4157	0.215	0.05	-4.243	Fail to reject H_0
	K	0.557	0.152	80	0	0.223	0.05	0.016	Fail to reject H_0
	EC	10.827	0.299	158	0	0.014	0.05	0.552	Reject H_0
	pH	0.369	0.655	346	0	0.0001	0.05	0.027	Reject H_0

Table 3.18. Significance testing of the trends in water quality parameters at Station W4R001Q01 between 1978 and 2012.

Station ID	Statistical results		Mann-Kendall trend test/two-tailed test						Interpretation
	Variable	Std. deviation	Kendall's tau	S	Var (S)	p-value (Two-tailed)	alpha	Slope	
W4R001Q01	PO_4	0.024	0.018	8	3140.667	0.901	0.05	4.500	Fail to reject H_0
	NO_3/NO_2	0.220	-0.462	-201	0.000	0.0002	0.05	-0.010	Reject H_0
	NH_4	0.022	-0.122	-53	3139.667	0.353	0.05	-3.333	Fail to reject H_0
	K	0.421	0.329	143	0.000	0.011	0.05	0.016	Reject H_0
	EC	15.789	0.306	133	0.000	0.018	0.05	0.276	Reject H_0
	pH	0.401	0.444	193	0.000	0.103	0.05	0.023	Fail to reject H_0

Station W4H013Q01

The faecal coliform data were available at this station and therefore these data were included in the assessment as well. A significant trend was detected for the NO_3/NO_2 and EC where the computed p-value (<0.0001 and 0.003) was found to be lower than significance value $\alpha = 0.05$ (Table 3.19). Visual inspection of graphic plots indicated an increasing trend for pH, EC and faecal coliforms and decreasing trend for NO_3/NO_2 (Figures 3.18 and 3.19). No trends could be detected in other variables tested indicating that these parameters were stable over the measurement period.

Table 3.19. Significance testing of the trends in water quality parameters at Station W4H013Q01 between 1984 and 2009.

Station ID	Statistical results		Mann-Kendall trend test/two-tailed test						Interpretation
	Variable	Std. deviation	Kendall's tau	S	Var (S)	p-value (Two-tailed)	Alpha	Slope	
W4H013Q01	PO_4	0.007	0.238	55.000	0.000	0.130	0.05	3.158	Fail to reject H_0
	NO_3/NO_2	0.141	-0.706	-63.000	0.000	0.0001	0.05	-0.014	Reject H_0
	NH_4	0.052	-0.299	-69.000	0.000	0.055	0.05	-0.001	Fail to reject H_0
	K	0.354	0.048	11.000	0.000	0.781	0.05	0.004	Fail to reject H_0
	EC	3.700	0.455	105.000	0.000	0.003	0.05	0.390	Reject H_0
	pH	0.305	0.255	59.000	0.000	0.103	0.05	0.02	Fail to reject H_0
	Faecal coliforms	388.974	0.500	18.000	0.000	0.075	0.05	80.854	Fail to reject H_0

Similarly to the upstream conditions, the Phongolo River downstream of the dam showed an increasing trend in pH, EC and salts but a decreasing trend in nutrients (NH_4, PO_4 and NO_3/NO_2). There was also an increase in faecal coliforms.

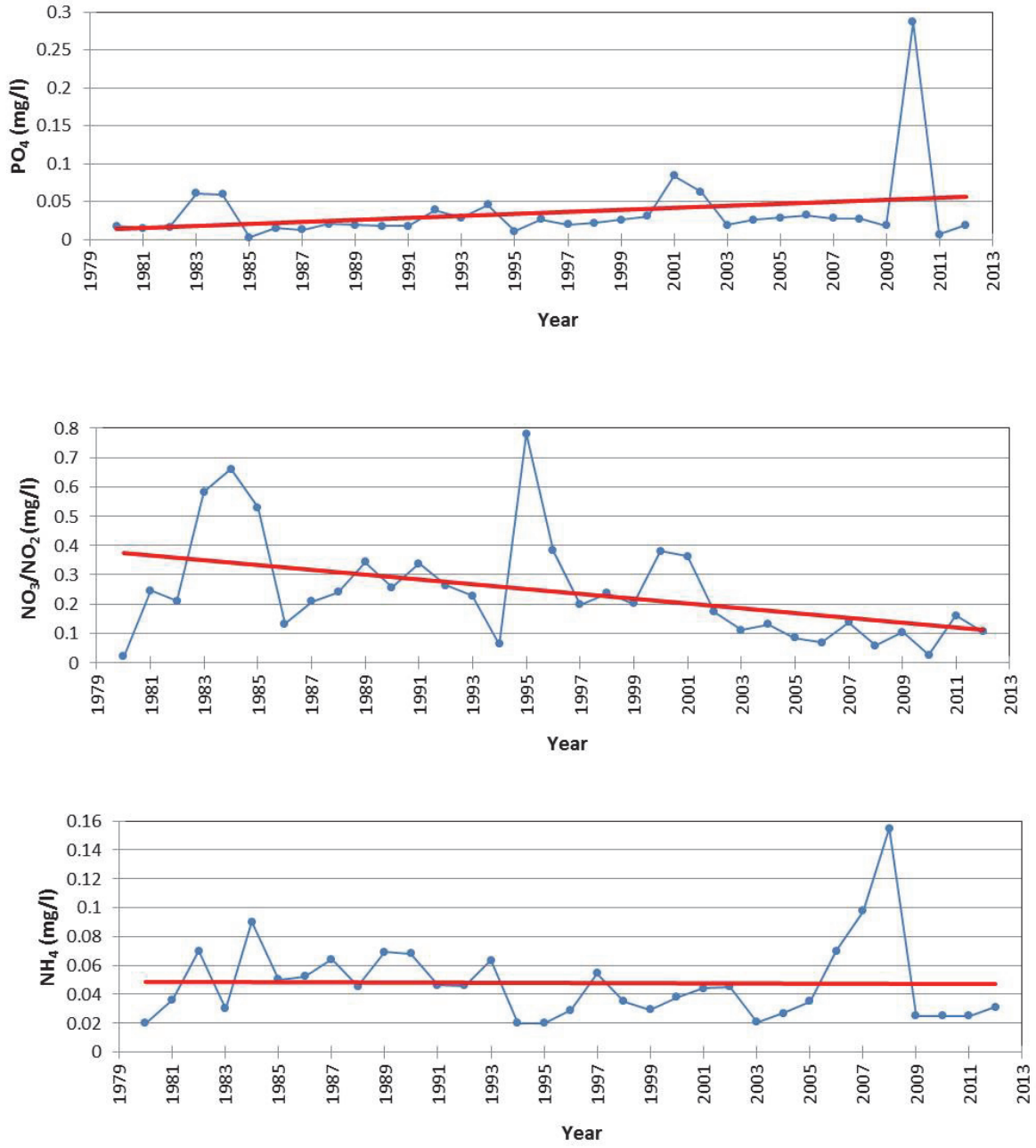


Figure 3.14. Trends in nutrient concentrations at Station W4H003Q01 between 1980 and 2012.

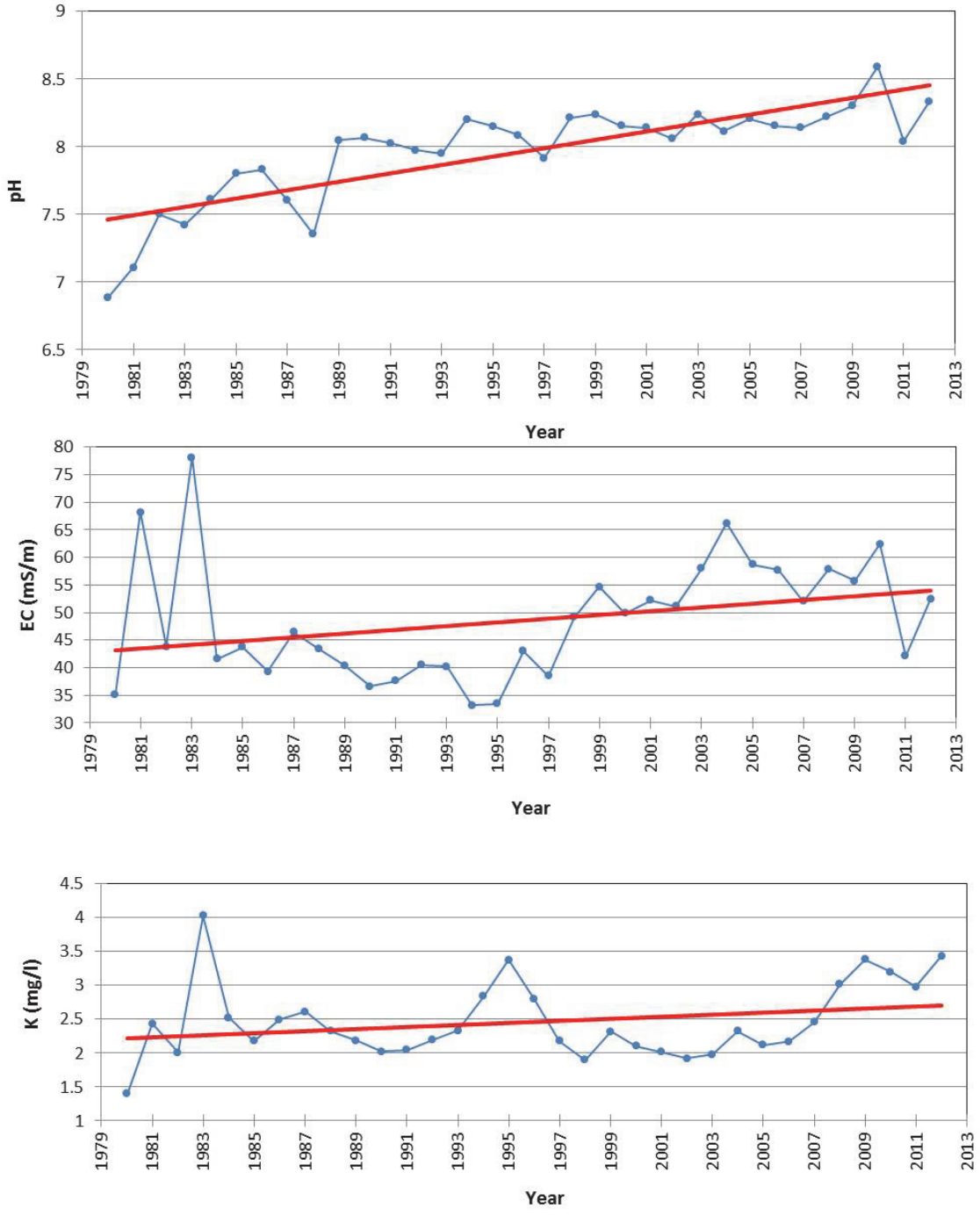


Figure 3.15. Trends in pH, electrical conductivity and K concentrations at Station W4H003Q01 between 1980 and 2012.

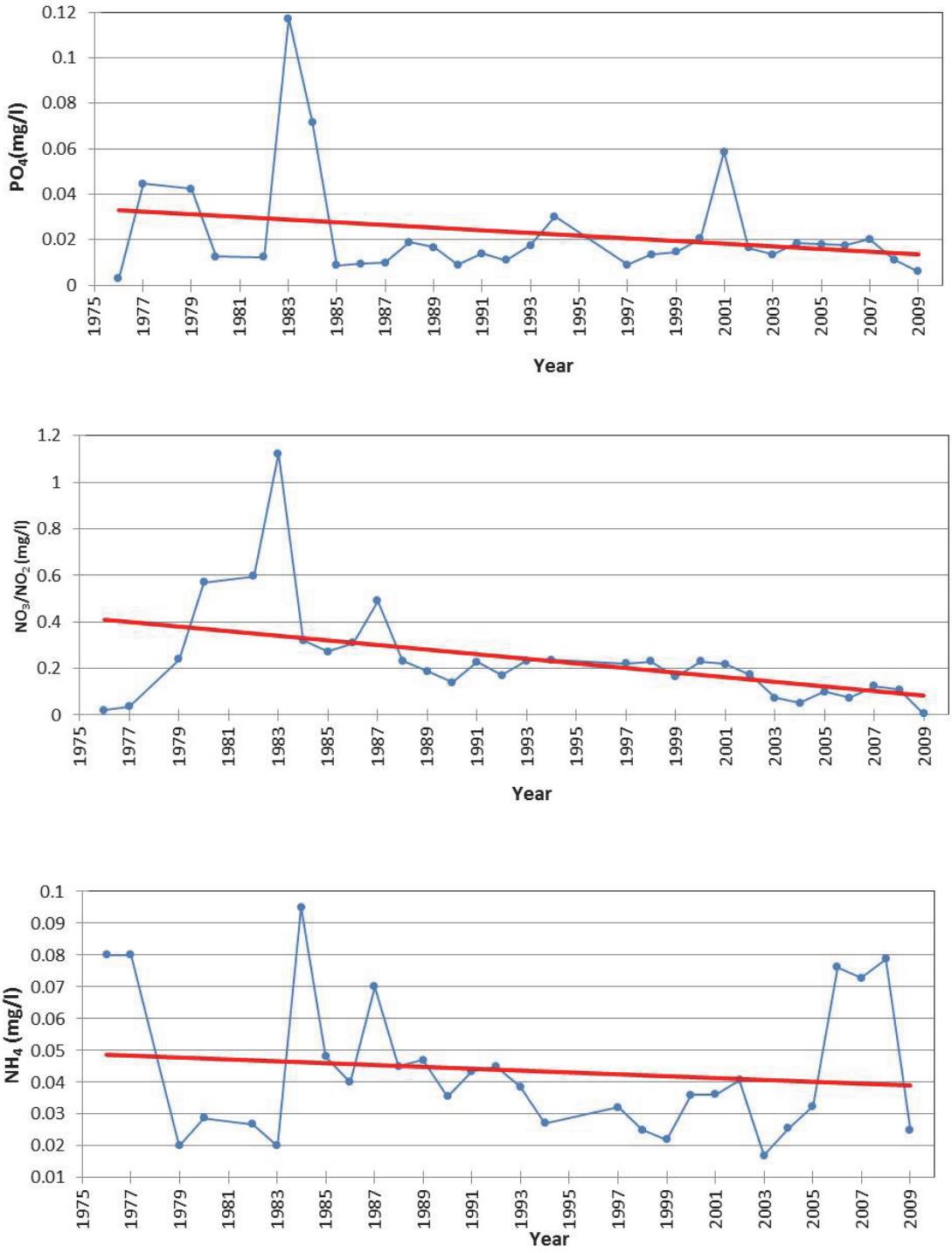


Figure 3.16. Trends in nutrient concentrations at Station W4R001Q01between 1978 and 2012.

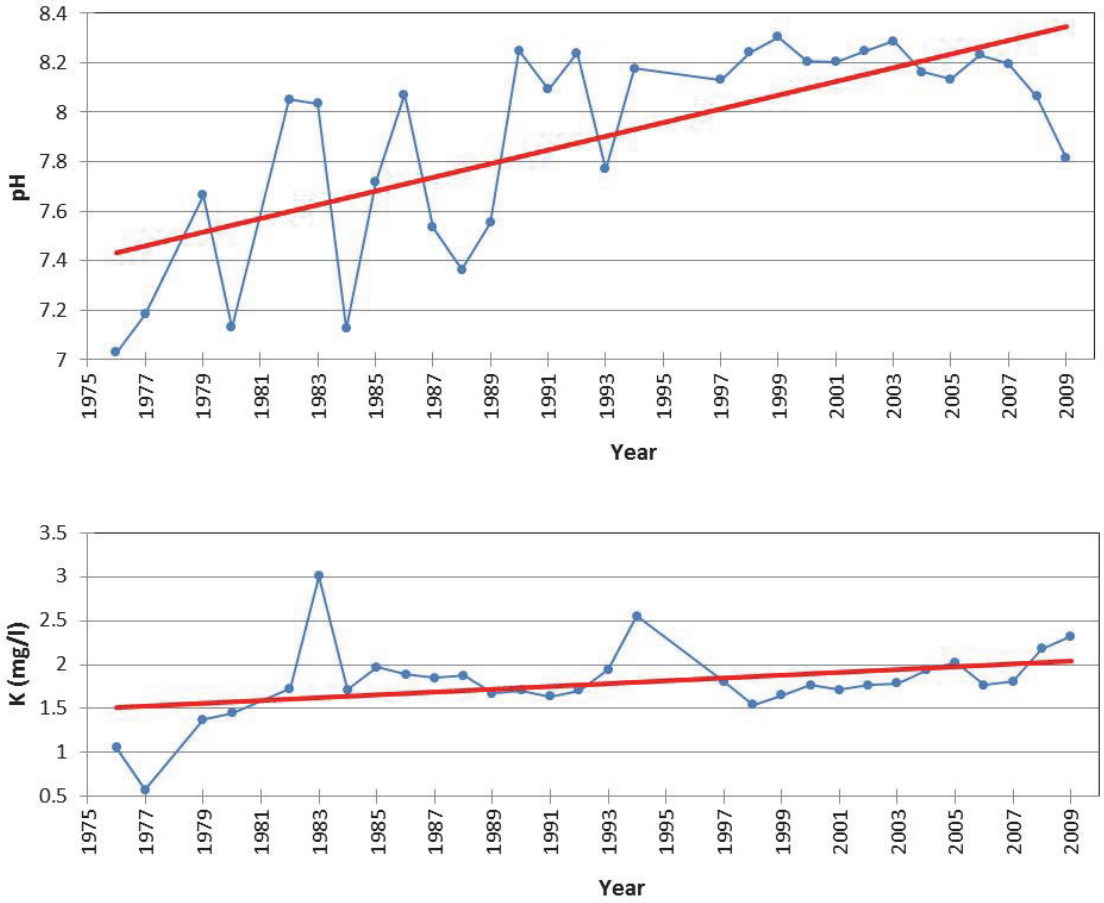


Figure 3.17. Trends in pH and K concentrations at Station W4R001Q01 between 1978 and 2012. Note that electrical conductivity (EC) data were not available.

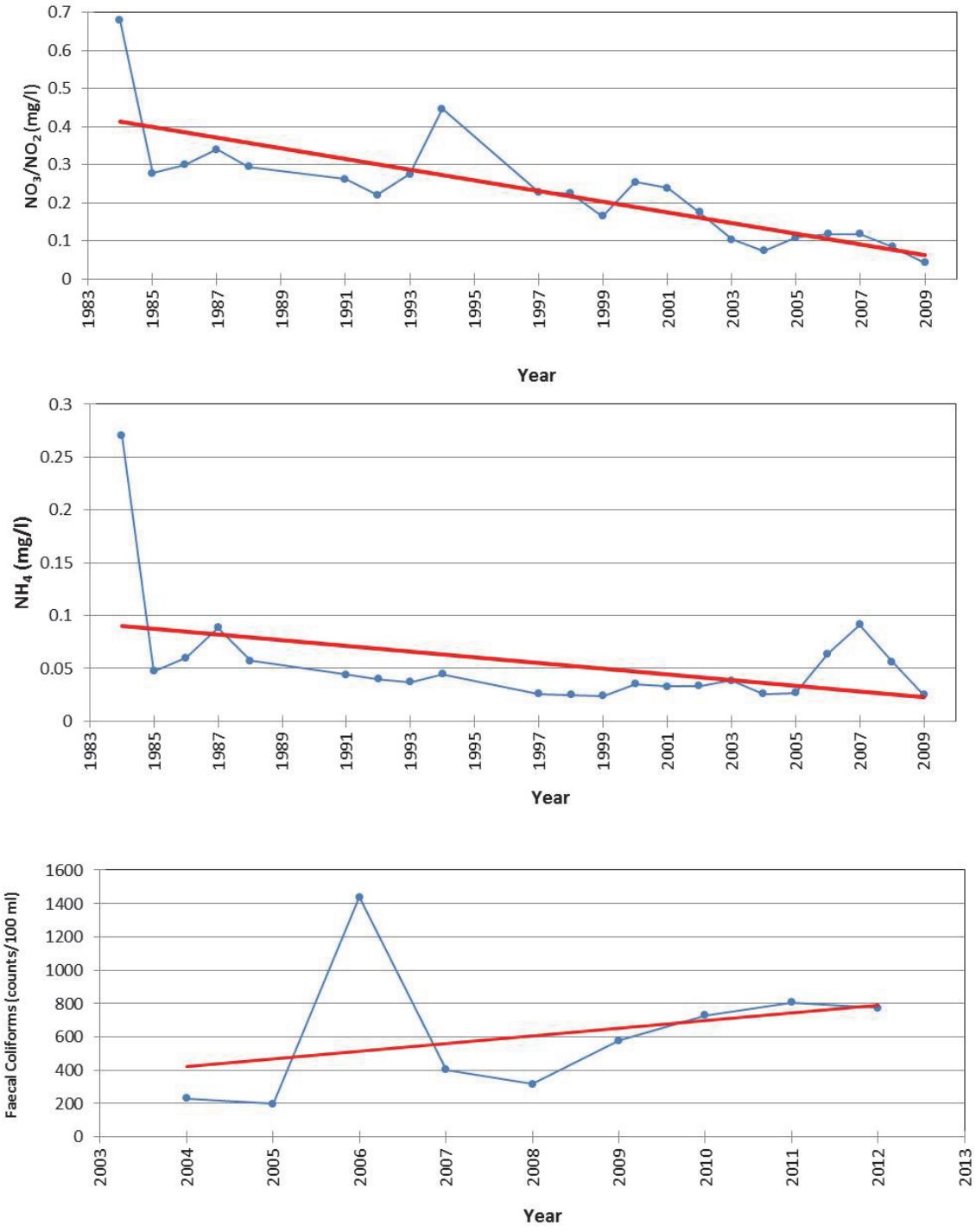


Figure 3.18. Trends in nutrient and faecal coliform concentrations at Station W4H013Q01 between 1984 and 2009. Note that no PO_4 data were included in this trend assessment.

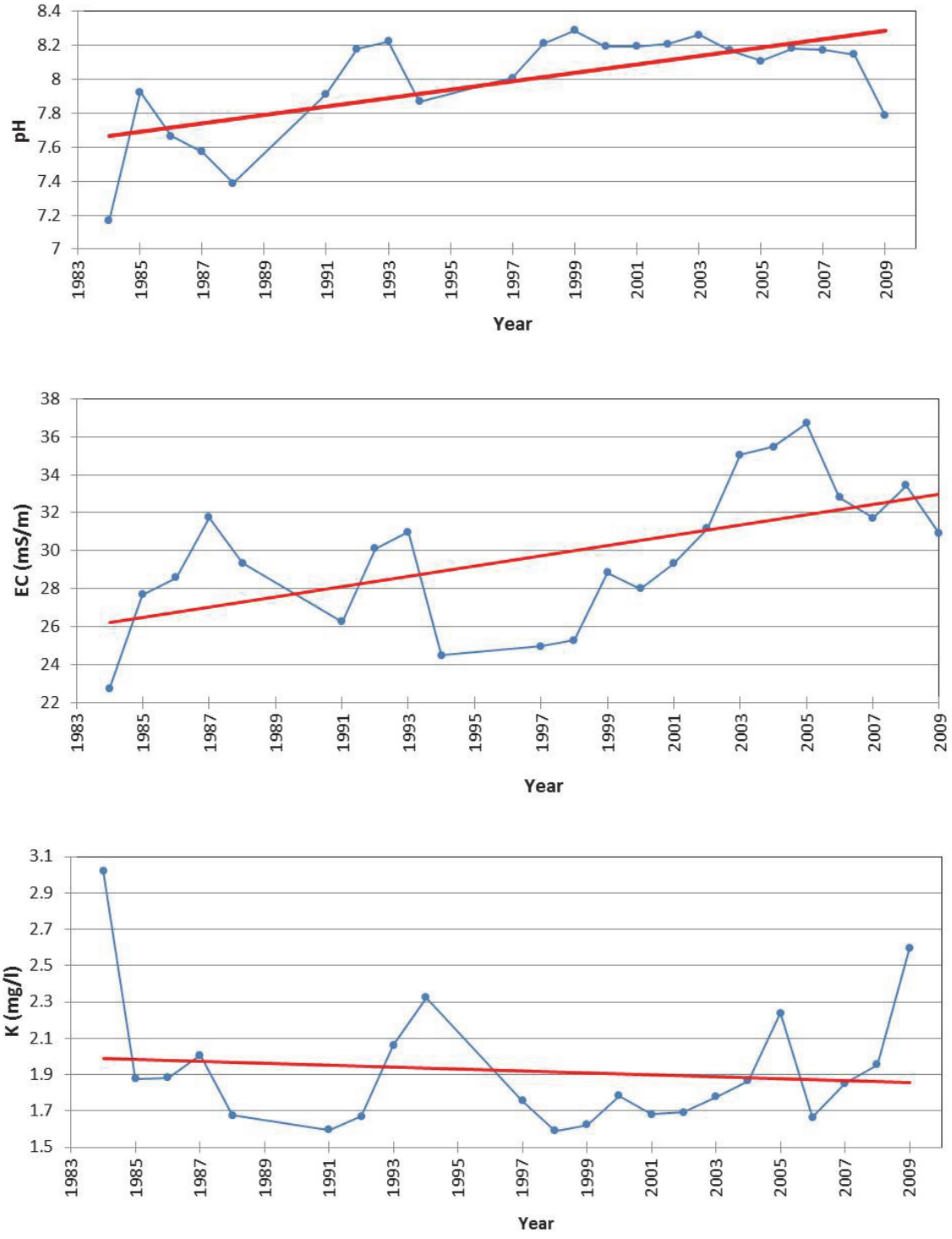


Figure 3.19. Trends in pH, electrical conductivity and K concentrations at Station W4H013Q01 between 1984 and 2009.

3.3.4 Physicochemical driver assessment index (PAI)

Historical water quality data of the Phongolo River up and downstream of the Pongolapoort Dam (1977 to 2012) were available to compare with the data collected during the 2012 and 2013 surveys. Data were collected from the eight riverine sites (Figure 2.2) along the Phongolo, Ngwavuma and Usutu Rivers downstream of the dam. The historical data were used to construct a reference condition and were used to adjust the benchmarks used in the PAI assessment (Kleynhans et al., 2005). As a part of the PAI assessment procedure, there is more than one model to assess the salts. For this project the EC was used as surrogate since the TEACHA salt model has not yet been finalised for implementation. Figures 3.20 and 3.21 present the distribution of EC across the existing upstream water quality monitoring stations (W4H003Q01, W4H006Q01, W4H011Q01, 188858 Illovo Sugar and 188865 Illovo Sugar discharge) as well as the downstream monitoring points (W4H007Q01, W4H008Q01, W4H009Q01, W4R001Q01, W4H013Q01 and W4H010Q01).

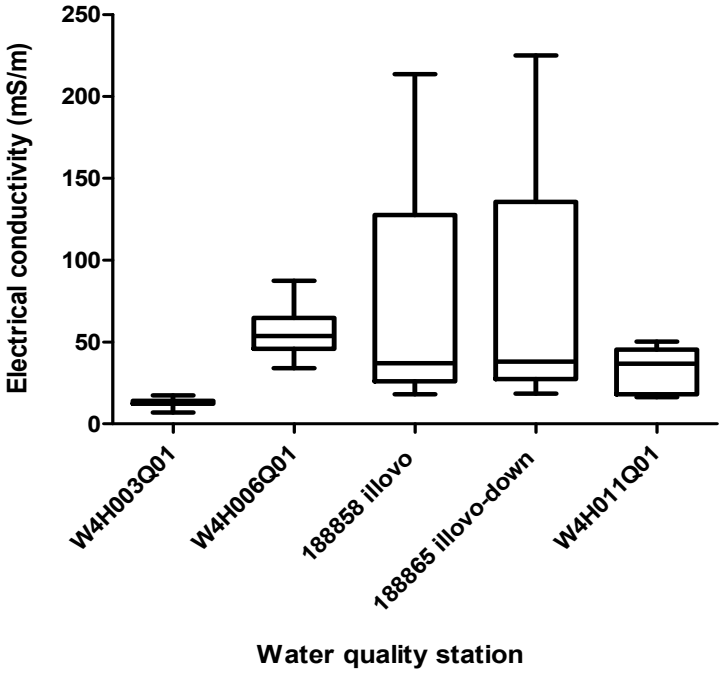


Figure 3.20. Box-and-whisker plots of the historical electrical conductivity (mS/m) readings obtained from DWA water quality monitoring stations upstream of the dam. Boxes represent the mean with the 5th and 95th percentiles while the error bars represent the minimum and maximum values.

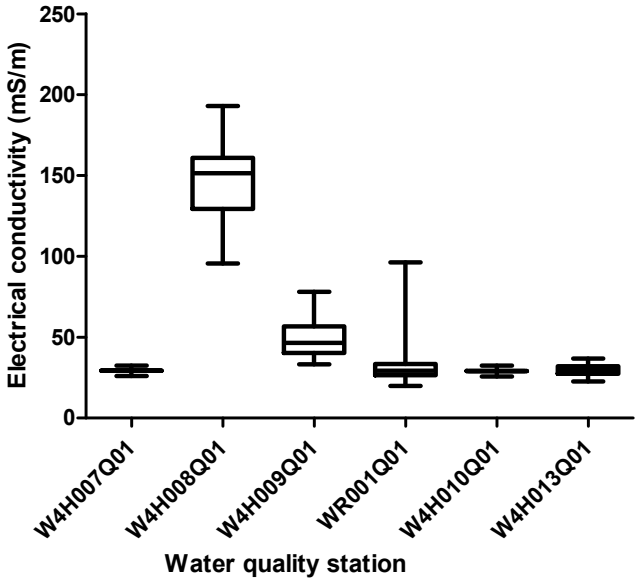


Figure 3.21. Box-and-whisker plots of the historical electrical conductivity (mS/m) readings obtained from DWA water quality monitoring stations downstream of the dam. Boxes represent the mean with the 5th and 95th percentiles while the error bars represent the minimum and maximum values.

The physicochemical water quality data recorded at Sites 3, 6 and 9 during November 2012 are presented in Table 3.20. The difference in water quality between the Ngwavuma River (Sites 4 and 5 in Table 3.21), Phongolo River (Sites 8), Nyamithi Pan outflow (Site 9) and the Usutu River (Site10) is noteworthy. This is apparent in the relatively high EC and TDS levels and low oxygen concentrations in the Ngwavuma River and at the Nyamithi outflow compared to the Phongolo (Site 8) and Usutu Rivers. The best water quality was recorded at Site 3 in the Usutu River during the three sampling periods. The elevated levels of solutes in the Ngwavuma River suggest that it could potentially impact on the water quality of the Phongolo River upstream of the Ndumo Nature Reserve.

The high EC values (Table 3.22) of the water at Sites 5 and 9 during April 2013 is noteworthy. These values are regarded as high for lotic freshwater systems. Site 5 is located downstream of the Ngwavuma settlement and the river may be affected by a variety of informal industrial activities (e.g. brick-making, car-washing) and domestic chores (e.g. laundry, bathing and washing). Water abstraction, sand-mining and brick-making are common occurrences along the river. The high conductivity at Site 9, which is the outlet of the Nyamithi Pan, is a natural phenomenon related to the chemical composition of the ancient marine bed on which the pan is situated, resulting in elevated solute concentrations in the water. The low oxygen concentration at Site 9 (2.21 mg/l) during April, which was markedly lower compared to all the other sites sampled, reflects anoxic conditions in the region of the pan outlet as can be expected from stagnant water bodies.

Table 3.20. The physicochemical water quality data collected during the November 2012 survey at selected sites on the Phongolo and Usutu Rivers.

	Site 3	Site6	Site 9
River	Phongolo	Usutu	Phongolo (pan outflow)
Temperature (°C)	25.6	25.2	25.1
EC (mS/m)	67	18	76
TDS (mg/l)	0.43	0.12	0.49
pH	7.73	7.71	7.78
Dissolved oxygen (mg/l)	5.1	7.8	6.1
Oxygen saturation (%)	74.1	94.6	73.4
Turbidity(NTU)	10.4	81.4	34.8

Table 3.21. The physicochemical water quality data collected during the April 2013 survey at selected sites on the Phongolo, Ngwavuma and Usutu Rivers.

	Site 1	Site 2	Site 4	Site 5	Site6	Site8	Site 9
River	Phongolo	Phongolo	Ngwavuma	Ngwavuma	Usutu	Phongolo	Phongolo (Nyamithi out flow)
Temperature (°C)	23.7	26.7	27.2	21.2	21.1	23.4	23.5
EC (mS/m)	26	29	104	91	186	32	1148
TDS (mg/l)	0.17	0.19	0.68	0.59	0.12	0.21	0.74
pH	7.38	7.6	8.67	8.45	8.09	7.79	7.45
Dissolved oxygen (mg/l)	10.2	9.6	6.76	5.76	10.2	7.2	2.21
Oxygen saturation (%)	120.6	101.1	87.4	65.3	126	85.2	25.7

Table 3.22 presents the water quality data recorded during July 2013. Results were comparable to results from April 2013, with relatively low conductivities recorded in the Phongolo River. High EC and TDS concentrations were recorded in the Ngwavuma River, which were markedly higher than those measured in the Phongolo Rivers but similar to levels in the Usutu River. The current findings are in contrast with the findings by DWA (2009). All three sites along the Ngwavuma River had similarly high EC levels, even though Site 4 was situated upstream of any formal or informal settlements.

Table 3.22. The physicochemical water quality data collected during the July 2013 survey at selected sites on the Phongolo, Ngwavuma and Usutu Rivers.

	Site 1	**Site 2**	**Site 4a**	**Site 4**	**Site 5**	**Site 6**	**Site 8**	**Site 9**
River	Phongolo	Phongolo	Ngwavuma	Ngwavuma	Ngwavuma	Usutu	Phongolo	Phongolo
Temperature (°C)	17.4	19.5	19.5	19.5	18.2	16.1	19.6	20.5
EC (mS/m)	26	38	86	83	85	28	12	215
TDS (mg/l)	0.17	0.25	0.56	0.54	0.55	0.18	0.09	1.39
pH	8.31	7.6	8.35	8.28	8.08	8.11	7.78	7.74

The results of the PAI assessment are presented in Table 3.23 and Figure 3.22 including the variables that contribute to the final scores obtained. The PAI model indicates that the water quality is generally in category C due to impacts upstream of the site.

Table 3.23. Summary of the final scores allocated to water quality variables and the final physicochemical driver assessment index (PAI) scores and associated present ecological state (PES) categories established in the study.

Dates		**pH**	**Salts**	**Nutrients**	**Temperature**	**Clarity**	**DO**	**Toxic**	**PES**	**Score**
Nov 2012	Site 6	1.5	1.5	1.5	2	0.5	1	1	C	75.48
	Site 8	1.5	1.5	1.5	2.5	2	1.5	1	C	68.49
	Site 9	1.5	1	1.5	2	2	1.5	1	C	70.86
Apr 2013	Site 1	0.5	1	1	1.5	2	1	1	C	76.99
	Site 2	0.5	1	1	2	1.5	1	1	B/C	77.42
	Site 4	1	1.5	1.5	2.5	1	1	1	C	71.83
	Site 5	1	1.5	1	1.5	1	1	1	C	75.48
	Site 6	2	1	1	1	1	1	1	B/C	77.85
	Site 8	1.5	1	1	2	1.5	1	1.5	C	73.12
	Site 9	1	1.5	1.5	2	1	2	1.5	C	66.45
Jul 2013	Site 1	0.5	1	1	0.5	1	1	1	B/C	80
	Site 2	1	1.5	1.5	1	1.5	1	1	C	75.7
	Site 4a	1.5	1	1	1	1	1	1	B/C	78.92
	Site 4	1.5	1.5	1.5	1	1	1	1	C	76.13
	Site 5	1.5	1	1.5	1	1.5	1	1	C	75.91
	Site 6	1.5	1.5	1.5	0.5	1	1	0.5	B/C	79.35
	Site 8	1.5	1.5	1.5	1	1	1	1	C	76.13
	Site 9	1	1.5	1.5	1.5	1.5	1	1	C	74.62

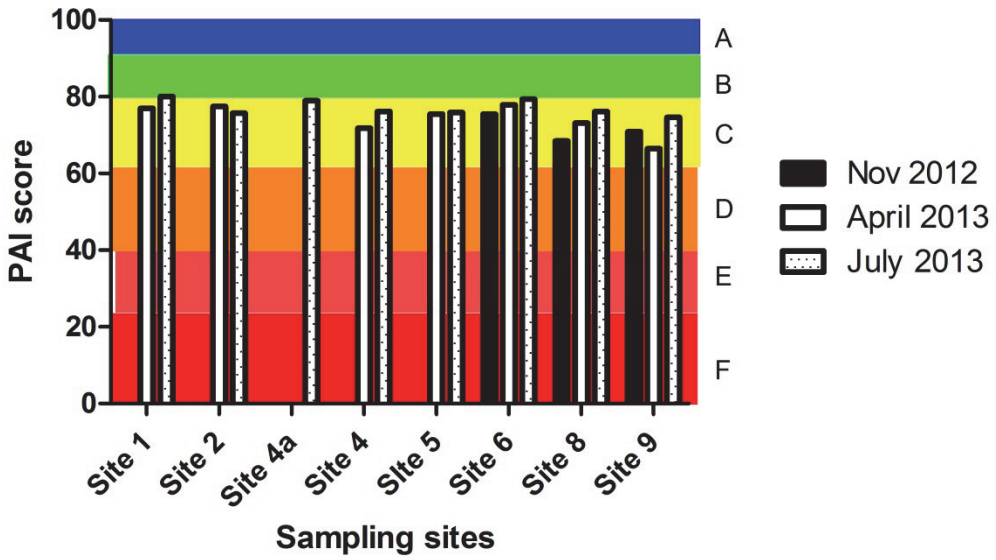


Figure 3.22. Physicochemical driver assessment index (PAI) scores with associated present ecological state (PES) categories derived for all sites.

When considering the data in terms of frequency and temporal variability it was evident that the historical data (data set between 1997 and 1987) has been consistently monitored over this period and could therefore be regarded as reliable. For the purposes of constructing reference conditions Palmer et al. (2005) recommend 95th and 50th percentiles of time series historical data be used. The number of data points available for most sites considered in this chapter (i.e. between 20-50) allows for a moderate to high assessment of the reference condition (DWAF, 2008). For the determination of the PES the data are less reliable since the availability of data points in the last three years is more fragmented. For the purposes of this study we used the water quality data collected at the study sites to construct the PES. Therefore if the criteria of DWAF (2008) were to be applied, the PES and resulting PAI score would be of low confidence.

The analyses of historical data for the area upstream of the Pongolapoort Dam indicate that the water quality is in a poor state. Almost all monitoring stations upstream indicated elevated levels of nutrients as well as salinity in the form of EC. These elevated nutrient levels can result in eutrophication of the water resources if not managed. Eutrophication caused by enrichment of the water body with nutrients is a major problem in most impoundments of South Africa. Should the extent of current upstream agricultural activities increase, eutrophication might become a problem in Pongolapoort Dam in the future.

The downstream monitoring stations have recorded a decreasing trend in nutrients (PO_4 and NH_4) over the past decades, while there has been an increase in salinisation (as measured in EC and K). The data also indicated low DO concentrations except for the Usutu River.

The Mann-Kendall trend analysis indicated increasing trends for PO_4 and pH at station W4H003Q01. An increasing trend was also detected for PO_4, NH_4, EC and pH at station W4H006Q01. All these variables are related to agricultural activities. The water quality downstream of the dam is also showing some major problems with an increasing trend in NO_3/NO_2, K, pH and EC at three monitoring stations including W4H009Q01, W4H013Q01 and W4R001Q01. The main drivers of the water quality status (present ecological state – PES) of the Middle Phongolo River upstream of the Pongolapoort Dam include releases from Pongola WWTW, cattle feedlots, small dams in tributaries, irrigation return flows, effluents from sugar mills and runoff from roads. The main drivers of changing water quality below the dam include water abstraction from Pongolapoort Dam for the Senekal irrigation scheme,, Jozini Waste Water Treatment Works, irrigation on the floodplain, livestock watering and encroaching human settlements. However, the study indicated that the Phongolo River water quality is generally classified as fair. In addition all of the water quality parameters that were measured are also within the recommended guideline values for aquatic ecosystems (DWAF, 1996).

3.4 Conclusions

The study aimed to determine the current water quality status (2012-2013) and historical trends in water quality (1970s-2010) in the middle and lower Phongolo River. The results of this study revealed that there is a general increase in particularly nutrient and salt (measured as EC) above and below the Pongolapoort Dam. Those parameters found to be higher compared to DWAF guidelines (DWAF, 1996) were subjected to trend analysis, and pH, PO_4, NO_3/NO_2 and K were found to be increasing in some monitoring points both upstream and downstream of the dam. Elevated levels of PO_4, NO_3/NO_2 and salts are most like due to irrigation return flows entering the dam as well as the river downstream of the dam. These findings are in agreement with Van der Laan et al. (2012) who also found that the quality of water used for irrigation in the northern sugarcane-producing regions of South Africa was deteriorating because of shazards posed by increased salinity and sodicity.

Under DWA's National Chemical Monitoring Programme (NCMP), the Phongola River has a good history of long-term physico-chemical data. However, key water quality determinants are not sampled at the NCMP sites, and those that are sampled reveal a limited number of records. Due to

the low confidence in available data for the last five to 10 years it is strongly recommended that continued routine water quality monitoring of Phongolo River, below the dam should be carried out. It would then allow for calculating the PAI and PES with a greater degree of confidence. Notwithstanding the low confidence in the PES outcomes it is evident that despite the general increases in nutrients and salts, The PAI classes of a B/C to C indicate that these parameters do not pose a risk to the aquatic ecosystem of the lower Phongolo River at present.

3.5 References

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4 ECOLOGICAL INTEGRITY STATE ASSESSMENT OF THE LOWER PHONGOLO RIVER

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4.1 Introduction

For this component of the project the EcoStatus determination protocol, as described by Kleynhans and Louw (2007), was followed. In this protocol selected biophysical attributes of a river (excluding the floodplain) are determined and compared to the natural or close to natural reference conditions (RC) in order to determine the present ecological state (PES) and complete the ecological classification process that will describe the EcoStatus of the river. The process provides insight and understanding into the causes and sources of deviations from the RC. Based on the findings it is also possible to derive desirable and attainable future ecological objectives for the specific river (Kleynhans & Louw, 2007).

The protocol consists of a number steps, of which the first four are listed below:

i. Determine reference conditions (RC) for each biophysical attribute.
ii. Determine the present ecological state (PES) for each attribute at the hand of a prescribed index.
iii. Determine the trend (i.e. moving towards or away from the reference condition) for each attribute component.
iv. Determine causes for the PES and decide whether these are flow or non-flow related.

In the steps listed above the following indices can be applied:

- Geomorphological driver assessment index (GAI) – as habitat assessment
- Fish response assessment index (FRAI)
- Macroinvertebrate response assessment index (MIRAI)
- Riparian vegetation response assessment index (VEGRAI)

In this project all the above indices were carried out at Level III (Kleynhans & Louw, 2007) as it was considered that this level would supply the information necessary to determine the current health status. The drivers were measured using the GAI and the *in situ* water quality parameters while

responses to the drivers were determined using fish (FRAI), macroinvertebrates (MIRAI) and the riparian vegetation (VEGRAI).

The obtained results of the biological indices can then be used to calculate the EcoStatus of the river reaches, using the method to determine the overall status of the Phongolo River. EcoStatus determination provides the ecological category for the instream and riparian vegetation PES as well as an ecological category for the reach (Kleynhans & Louw, 2007).

Based on the results of the EcoStatus determination the process can be taken a few steps forward to provide recommendations for the management of rivers. These further steps (v-vii) can be regarded as a continuation of steps i-iv given above:

v. Determine the ecological importance and sensitivity (EIS) of the biota and habitat.
vi. Considering the PES and EIS, suggest a realistic and practically attainable recommended ecological category (REC) for each component and the EcoStatus.
vii. Determine alternative ecological categories (ECs) for each component as well as for the EcoStatus for the purposes of providing various scenarios.

4.2 Methodology

4.2.1 Habitat assessment

During the habitat surveys, geomorphological driver assessment index (GAI) field forms were used to capture the data. The observed impacts in the area were recorded and in addition with Google Earth images used to determine impacts in the various catchments. Sites and impacts were photographed and this information will be used to monitor future changes to the sites and for comparison to historical photographs if available.

The information related to impacts in the river reaches were applied to the appropriate risk regions and later used as part of the management strategy and risk assessment when the recommendations for the management plans were made.

The complete process, and in particular steps v to vii, is illustrated in Figure 4.1.

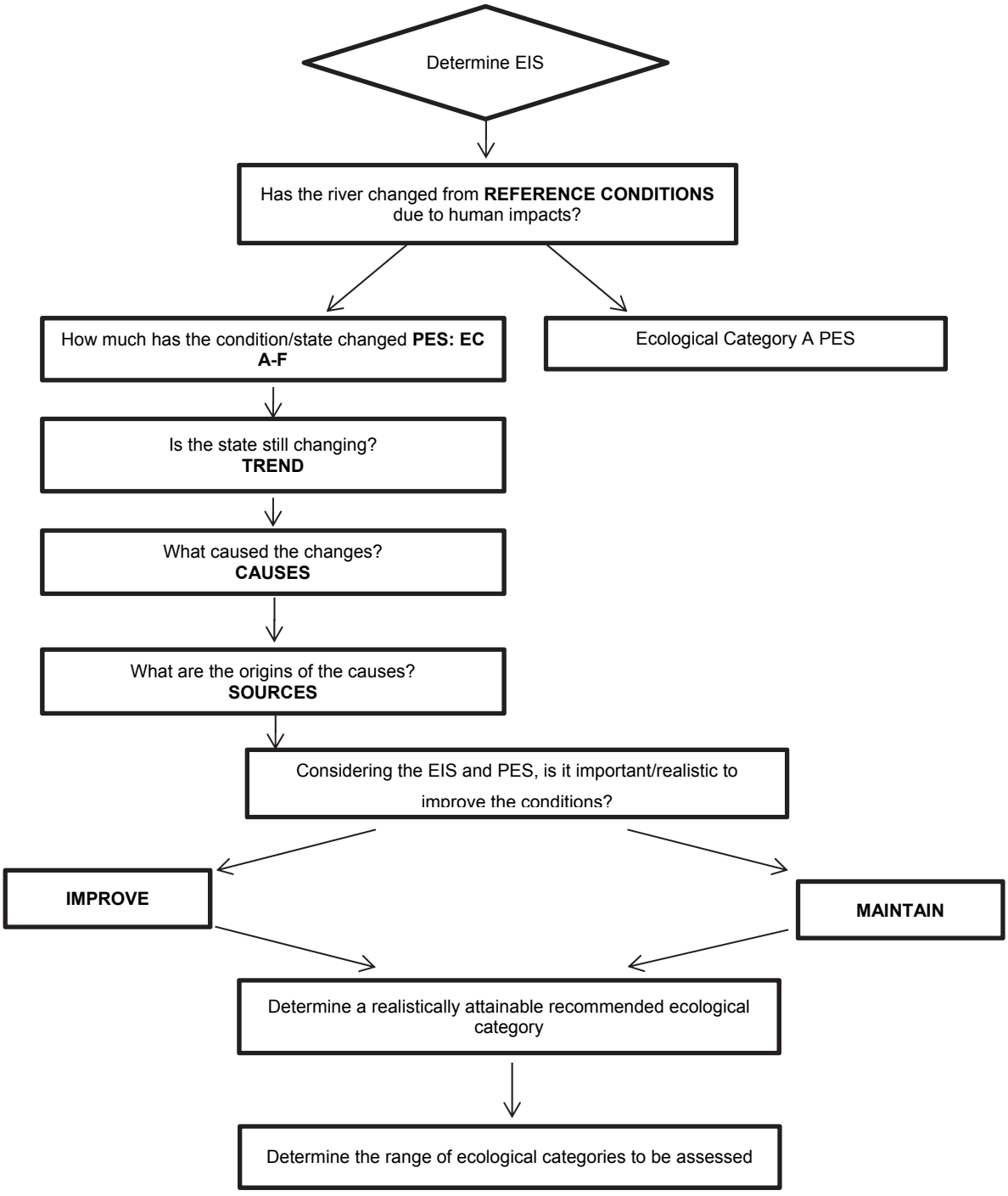


Figure 4.1. A flow diagram illustrating information generated to determine the ecological categories (adapted from Kleynhans & Louw, 2007).

4.2.2 Macroinvertebrates

Macroinvertebrate sampling followed the standard SASS5 protocol (Dickens & Graham, 2002). Three macroinvertebrate biotope types were sampled at each site, these being: a) stones-in-

current/stones-out-of-current; b) marginal vegetation; and c) gravel, sand and mud using a standard SASS net. In order to assist with positive identification of the different taxa, all the collected specimens were preserved in 4% formaldehyde and transported back to the laboratory where the WRC series of Guides to the Freshwater Invertebrates of Southern Africa and appropriate field guides were used to identify the different representatives of the invertebrate families.

The SASS and ASPT scores from the present study were plotted against historical data from the Lowveld Ecoregion as provided by Dallas (2007). Changes in the macroinvertebrate community structure during high- and low-flow periods were analysed using cluster and NMDS ordination techniques in PRIMER (PRIMER Statistical Package) (Clarke, 1993). The SASS5 data were also used to calculate the macroinvertebrate response assessment index (MIRAI) scores (Thirion, 2007). This index is based on the environmental intolerances and preferences of macroinvertebrates and their resultant response to changes in environmental drivers or metrics (Kleynhans & Louw, 2007). Reference data for the determination of the ecological category for macroinvertebrates were obtained from RHP Site W4PONG-N2PON, a site located just upstream of the Pongolapoort Dam. The site was sampled under high- and low-flow conditions by the Coastal Research Unit of Zululand (CRUZ) in 1998, prior to the construction of the Paris Dam in the Bivane River, a major tributary of the Phongolo River (Vivier & Cyrus, 2000). With the exception of Site 4 for which there was a once-off set of SASS5 data from 2012, no reference data were available for any of the study sites. The reference site lies in the Lowveld Lower ecoregion, as do Sites 2, 3, 5 and 6. In view of the lack of reference data for the Lebombo Uplands sites (Sites 1, 4a and 4), and given that Sites 1 and 4a lie right on the border between the Lowveld and Lebombo Uplands ecoregions, it was felt that the existing reference data could be used for the Lebombo Uplands sites, albeit with a slightly reduced level of confidence.

4.2.3 *In situ* physicochemical parameters

During each survey a suite of physicochemical water quality parameters were measured at each sampling site using a YSI 9260 water quality meter and included:

- Temperature (ºC)
- Electrical conductivity (mS/m)
- TDS (mg/L)
- pH
- Dissolved oxygen saturation (%)
- Dissolved oxygen concentration (mg/L)
- Turbidity (NTU)

4.2.4 Riparian vegetation

At each site the riparian vegetation was assessed using a combination of the field protocol described by Kemper (2001) and Kleynhans et al. (2007b). The vegetation response assessment index (VEGRAI) scores were calculated at a Level III assessment level according to the method described by Kleynhans et al. (2007b).

4.2.5 Fish

At each site the available fish habitat was classified based on the velocity and depth parameters described by Kleynhans (2007) and in each habitat type, or velocity-depth class, the extent of the potential cover for the fish, namely substrate, overhanging vegetation and undercut banks, was estimated and scored. During each survey the existing conditions, which included turbidity, water colour and flow, were observed and recorded. Fish were sampled at the sites according to the habitat specific protocol described by Kleynhans (2007) and the collected fish specimens were identified on site using the key provided by Skelton (2001). The data were used to calculate fish response assessment index (FRAI) scores (Kleynhans, 2007). This index is based on the environmental intolerances and preferences of fish and their resultant response to changes in environmental drivers (Kleynhans, 2007). The reference state (RS) for each site was calculated based on the frequency of occurrence (FROC) data provided by Kleynhans et al. (2007a).

4.3 The selected sites

The site selection for the study was based on a number of considerations which included the availability of historical data, current impacts, and the distribution of sites within the ecoregions (see Chapter 2 for a detailed description of the sites).

Two ecoregions, namely Lebombo Upland (Ecoregion 12) and Lowveld (Ecoregion 3), formed part of the study area (Figure 4.2) and six sites were selected to represent the main rivers associated with the two ecoregions.

On the Phongolo River, Site 1 is immediately downstream of the Pongolapoort Dam wall and lies within the Lebombo Upland Ecoregion. The second site (Site 2) is downstream and lies at the start of the Lowland Ecoregion while Site 3 is in the Ndumo Game Reserve close to where the river crosses the border between South Africa and Mozambique.

Of the three sites along the Ngwavuma River, two sites (Sites 4a and 4) were in the Lebombo Upland Ecoregion. These two sites were selected to determine the impacts related to urbanisation between the point where the river crosses the border between Swaziland and South Africa (Site 4a)

and the area downstream where it exits the ecoregion (Site 4). The third site (Site 5) is in in the Lowveld Ecoregion close to the Phongolo River confluence.

Along the Usutu River only one site was selected with the intention that it should serve as a reference site for the Phongolo River. The selected site, Site 6, is located in the Ndumo Game Reserve close to the Phongolo River confluence and falls within the Lowveld Ecoregion.

4.4 Results

During the project a pilot survey was conducted to identify sampling sites (August 2012) and three surveys were completed; Table 4.1 shows the survey dates and the protocols applied during each survey.

Table 4.1. The sampling dates and protocols applied during the surveys (FRAI: fish response assessment index; VEGRAI: vegetation response assessment index; MIRAI: macroinvertebrate response assessment index; GAI: geomorphological driver assessment index).

Date	**Site number**	**FRAI**	**VEGRAI**	**MIRAI/ SASS5**	**GAI**	***In situ* physico-chemical parameters**
18 August 2012	Site 2	Yes	yes		yes	yes
18 November 2012	Site 5	Yes	yes	yes	yes	yes
14 November 2012	Site 3	Yes	yes	yes	yes	yes
16 November 2012	Site 6	Yes	yes	yes	yes	yes
16 April 2013	Site 1	Yes	yes	yes	yes	yes
16 April 2013	Site 2	Yes		yes		yes
17 April 2013	Site 4	Yes	yes	yes	yes	yes
18 April 2013	Site 5	Yes		yes		yes
19 April 2013	Site 3	Yes		yes		yes
20 April 2013	Site 6	Yes		yes		yes
28 July 2013	Site 1	Yes		yes		yes
28 July 2013	Site 2	Yes		yes		yes
29 July 2013	Site 4a	Yes	yes	yes	yes	yes
29 July 2013	Site 4	Yes		yes	yes	yes
29 July 2013	Site 5	Yes		yes		yes
30 July 2013	Site 3	Yes		yes		yes
30 July 2013	Site 6	Yes		yes		yes

4.4.1 Habitat assessment

The descriptions that follow are based on the visual observations of the geomorphology and the impacts at the sites.

Site 1

The site is immediately downstream of Pongolapoort Dam and the impacts are related to the flow releases from the impoundment. During low-flow release conditions, a regulated discharge of around 8 m^3/s is maintained, while during simulated floods the discharge is increased to between 600 and 800 m^3/s, depending on the water level in the impoundment (Lankford et al., 2011). The high discharge occurs over a short period spanning from two to four weeks and the main objective of this discharge is to ensure that water inundates the floodplain and in particular the pans in the floodplain.

This reach of the river is in a lower foothill region, just before the river spills onto the Makhathini floodplains where it flows in a narrow valley with steep river banks with remnants of a flood bench. The riverbed is dominated by cobbles and small boulders and probably because of flow regulation and the close proximity to the impoundment, very little sedimentation is present. However, small amounts of finer deposits are present on the vegetated islands. During low flows a backwater, secondary channels and vegetated islands are present and therefore one can classify the channel pattern during these flows as anabranched.

The site impacts observed included trampling by domestic animals, a road on the flood bench, dumping of domestic refuse and a picnic area. The riparian vegetation is modified and the vegetation present is in fair condition, but impacted by grazing and limited wood harvesting, with few alien invasive specimens present.

Site 2

This site is approximately 12 km downstream of the Pongolapoort Dam and is situated where the river can be classified as a lowland river. Because of the close proximity of the upper riparian zone/terrestrial interface, the surrounding landscape can be described as a “floodplain confined on the right-hand side”, as there are steep banks on this side of the river. The river channel pattern can be described as anabranching with a gentle slope and the study area is dominated by pools, cobbled riffles, vegetated islands and bars.

Impacts relate both to the upstream flow releases and agriculture. On the right-hand bank intensive farming of sugar cane and cash crops is present while the area adjacent to the left-hand bank is dominated by subsistence farming of cash crops, cattle and goats. Extensive trampling by the cattle and wood harvesting increases the erosion potential of the river banks. The riparian vegetation is compromised through the cutting of trees and grazing of saplings, but areas with good cover are still

present. Sand-mining of the river bed and banks during low-flow periods is extensive and includes the use of heavy equipment and vehicles.

There is evidence of the modified flow regime and erosion of the river banks at the study site. Some alluvial deposits are present, but the high discharges are responsible for removal of most fine sediments and sand. Local erosion during rain events contributes some fine-grained alluvial material between flood events.

Site 3

This site is located along a secondary channel of the Phongolo River within the Ndumo Game Reserve and is in the floodplain area where pans occur. The channel pattern can be described as anabranching with fine-grained alluvial deposits instream and on the river banks between the main channel and the secondary channel. The impacts observed at the site are mostly related to activities in the catchment and include trampling by domestic animals and removal of vegetation resulting in high silt loads. This can be linked to the flow modification that results from the management of flow and flow releases from the Pongolapoort Dam. During high flood releases, bed scour (sediment transport) may occur, but abstraction by the farmers outside the reserve results in lower velocities at the site and therefore sedimentation takes place. Local impacts are the pump station (abstraction of water for the campsite and staff village) and the old suspension bridge upstream of the site, but these have limited effects on the habitat of the site.

The active channel is approximately 15 m wide with a muddy and silty bottom and no cobbles or boulders are present. There is some sand in the pools on the exposed islands and bars, but the soft sediments dominate the substrate. The riparian vegetation is in a good condition with limited alien invasives present. Erosion of the river banks due to the flood releases is present.

Site 4a

Rock steps, boulders, pools and riffles are the dominant features of the hydraulic control while flat sand beds dominate the downstream area of this site. Both the marginal and riparian vegetation is in a good condition and limited impacts of alien invasive species and trampling by cattle were observed. The impact of the road and low bridge that forms part of the Cecil Macks Pass on the right-hand bank site was rated as medium. The burning of the vegetation on the steep mountain slopes of the gorge is a concern, as this will increase erosion and therefore lead to increased siltation in the river.

Site 4

This site on the Ngwavuma River is downstream of the residential area of the town of Ingwavuma. The observed physical impacts are the road bridge and the old low-water crossing. In addition, there is water abstraction, washing of clothes and vehicles in the river, dumping of refuse and an extensive brick-manufacturing operation with water abstraction and sand-mining of the river banks.

Where the river exits the Lebombo Mountains upstream of the site the slopes are steep and the villages with associated infrastructure in that area lead to high amounts of erosion. This is exacerbated by the increased runoff and erosion caused by stock trampling, grazing, cultivation and infrastructure development on the mountain slopes.

The valley profile at the site can be described as “V-shaped” with a single-thread channel pattern. The instream habitat includes pools, riffles, sand bars and instream and marginal vegetation (mostly heavily grazed sedges). The riparian vegetation is severely modified as most of the natural vegetation has been removed and dense stands of exotic plants are present.

Site 5

The river reach can be classified as a lowland river and the site is closely associated with the floodplain on either side. At Site 5, the river can be described as a single channel system with a pool-riffle-pool sequence and shallow backwaters and a side bar adjacent to the left bank consisting of coarse-grained alluvial material. The river water diverted into pipes under the bridge causes an increase in water velocity, resulting in erosion downstream of the structure. At the site the river banks are steeper than upstream of the bridge which could be an indication of the amount of erosion caused by the increased velocity.

The impacts at the site consist of stock trampling and wood collection in the riparian zone resulting in invasive plants dominating the understory of the riparian vegetation. Erosion of the river banks is moderate, but is enhanced by the bridge (downstream) and the dirt roads in the riparian zone contribute to erosion. During the surveys in late 2013 and early 2014, bridge construction activities were noted. A water abstraction point was constructed and this resulted in a stream diversion and silting of the system downstream of the site.

Land use around the site is dominated by subsistence farming and rural residential areas. Dumping of solid waste was noted and this impacts on the river and its biota. The surrounding catchment is modified with large areas cleared of the natural vegetation for subsistence cultivation. In many areas the riparian vegetation was removed and cultivated fields are encroaching on riparian zones.

Limited abstraction in the upstream region was observed and the exposed river banks are eroded. Deductions can be made that this will increase the water temperature as the shading effect is lost. Stock trampling and over-grazing is evident in the catchment and this further contributes to erosion.

Site 6

The river at this site is a single channel with large amounts of fine-grained alluvial deposits present and it can be classified as a lowland river. The channel is deeply incised with a steep right-hand bank upstream of the site. There is a flood bench on the right-hand bank of the river at this site and although signs of erosion are present, it is not severe. The riparian vegetation is in a good condition with some alien invasives present, especially on the left-hand bank. The streambed is dominated by coarse sand with some finer silt deposits in the backwaters and slow-flowing sections. There are some lee bars and a mid-channel bars, but no vegetated islands are present at the site.

This catchment has been severely impacted, mainly due to impoundments and commercial farming activities in Swaziland. The rural villages and stock grazing on the left-hand bank can further contribute to negative impacts (e.g. erosion, return flows and raw sewage) on the river. During the surveys, limited wood harvesting in the riparian zone was observed.

4.4.2 *In situ* physicochemical conditions

The physicochemical water quality conditions recorded at Sites 3 and 6 during November 2012 are shown in Table 4.2. The difference in water quality between the Ngwavuma River (Sites 4 and 5), Phongolo River (Site 3), and the Usutu River (Site 6) is noteworthy. This is apparent in the higher conductivity and TDS levels and low oxygen concentrations in the Ngwavuma River compared to the Phongolo River (Site 3) and Usutu River. The best water quality was recorded at Site 6 on the Usutu River. The high levels of solutes in the Ngwavuma River suggest that there are water quality issues in the Phongolo River upstream of the Ndumo Game Reserve, which is not apparent in the Usutu River.

The high electrical conductivity levels (Table 4.3) recorded at Sites 4 and 5 during April 2013 should be noted as this is regarded as high for lotic freshwater systems. Site 4 is located downstream of the Ingwavuma settlement and a variety of informal industrial activities such as brick-making and a car wash and domestic activities, such as doing the laundry, are regarded to be affecting the river. Water abstraction, sand-mining and brick-making are common occurrences along the river.

Table 4.4 presents the water quality data recorded during the July 2013 survey and are similar to the April 2013 results, with relatively low electrical conductivity values in the Phongolo and Usutu Rivers. High electrical conductivity values and TDS concentrations were recorded in the Ngwavuma River, which were higher than those recorded in the Phongolo and Usutu Rivers. All three sites on the Ngwavuma River site had high and similar electrical conductivity levels, even though Site 4a was upstream of any formal or informal settlements. The source of these high conductivity and TDS concentrations is unknown.

Table 4.2. Details of the sampling sites during November 2012 and the physicochemical water quality data at each site.

	Site 3	**Site 6**
River	Phongolo	Usutu
Habitat score (IHAS)	56	55
Temperature (°C)	25.6	25.2
Conductivity (mS/m)	67	18
TDS (mg/L)	0.43	0.12
pH	7.73	7.71
Dissolved oxygen (mg/L)	5.1	7.8
Oxygen saturation (%)	74.1	94.6
Turbidity (NTU)	10.4	81.4

Table 4.3. Details of the sampling sites during April 2013 and the physicochemical water quality data at each site.

	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**
River	Phongolo	Phongolo	Phongolo	Ngwavuma	Ngwavuma	Usutu
Habitat score (IHAS)	71	69	49	58	56	63
Temperature (°C)	23.7	26.7	23.4	27.2	21.2	21.1
Conductivity (mS/m)	26	29	32	104	91	186
TDS (mg/L)	0.17	0.19	0.21	0.68	0.59	0.12
pH	7.38	7.6	7.79	8.67	8.45	8.09
Dissolved oxygen (mg/L)	10.2	9.6	7.2	6.76	5.76	10.2
Oxygen saturation (%)	120.6	101.1	85.2	87.4	65.3	126

Table 4.4. Details of the sampling sites during July 2013 and the physicochemical water quality data at each site.

	Site 1	Site 2	Site 3	Site 4a	Site 4	Site 5	Site 6
River	Phongolo	Phongolo	Phongolo	Ngwavuma	Ngwavuma	Ngwavuma	Usutu
Habitat score (IHAS)	66	72	55	82	59	58	67
Temperature (°C)	17.4	19.5	19.6	19.5	19.5	18.2	16.1
Conductivity (mS/m)	26	38	12	86	83	85	28
TDS (mg/L)	0.17	0.25	0.09	0.56	0.54	0.55	0.18
pH	8.31	7.6	7.78	8.35	8.28	8.08	8.11

4.4.3 Integrated Habitat Assessment System (IHAS)

November 2012: The Integrated Habitat Assessment System (IHAS) scores for aquatic macroinvertebrates for Sites 3 and 6 during November 2012 are listed in Table 4.2. Due to the nature of floodplain reaches of rivers, the sampling sites were characterized by turbid, slow-flowing water and muddy banks with only limited rocky habitat. Where rocks were not present as a sampling habitat, submerged logs were used as substitute. The IHAS scores were relatively low throughout the system.

April 2013: The Integrated Habitat Assessment System (IHAS) scores recorded during April 2013 are presented in Table 4.3. The relatively high IHAS scores for Sites 1 and 2 are related to the mixture of macroinvertebrate habitats found in these areas. Site 1 is located immediately downstream of the Pongolapoort Dam and the water at this site is very clear and fast-flowing, resulting in the absence of sediment deposition. In contrast, the relatively low IHAS score of Site 3 is related to the lack of rocky and stony habitat and the generally muddy substrate, a natural characteristic of coastal floodplain rivers.

July 2013: The Integrated Habitat Assessment System (IHAS) scores recorded during July 2013 are presented in Table 4.4. Results were comparable to those recorded during April (Table 4.3), with relatively high scores at Sites 1 and 2 on the Phongolo River and on the Usutu River. Site 4a on the upper Ngwavuma River was sampled for the first time and had the highest IHAS score due to diverse aquatic biotope types and marginal vegetation with little evidence of human interference, while markedly lower scores were recorded in the lower Ngwavuma River downstream of Ingwavuma.

4.4.4 Macroinvertebrates

SASS5

During the November 2012 survey the macroinvertebrates in the Phongolo and Usutu Rivers were sampled at two sites, one on the Phongolo River system (Site 3) and one on the Usutu River (Site 6). In April 2013, the Phongolo River was sampled at Sites 1, 2 and 3, the Ngwavuma River at Sites 4 and 5 and the Usutu River at Site 6. The same sites were sampled in July 2013, with Site 4a in the upper Ngwavuma River added.

November 2012: The results of the SASS5 monitoring during November 2012 for Sites 3 and 6 are presented in Table 4.5. The SASS scores for the two sites during November 2012 were relatively low compared to April 2013, ranging from 89 at Site 6 to 94 and Site 6. The number of taxa per site ranged between 16 and 19 which are not low when one considers the lack of fast-flowing water and instream rocky habitat. The ASPT scores ranged from 5.2 at Site 3 to 5.7 at Site 6. An outstanding characteristic of the two sites is the marked difference in species composition between the Phongolo River site (Site 3) and that of the Usutu River (Site 6). A number of relatively sensitive taxa, such as Heptagenidae and Oligoneuridae, were present in the Usutu River but not in the Phongolo River. This indicates that although fewer taxa were recorded in the Usutu River, more sensitive taxa were present due to better habitat and water quality. This is reflected in the higher ASPT score of 5.7 in the Usutu River.

April 2013: The results of the SASS5 monitoring during April 2013 are presented in Table 4.6 and Figures 4.2-4.4. Highest SASS scores were recorded at Sites 2, 3 and 6. The relatively high scores at Site 3 are surprising given the limited SIC and SOOC habitat, but this is due to the high number of taxa and the presence of a number of sensitive organisms such as Oligoneuridae and Heptagenidae. The presence of these taxa at this site and Site 6 is indicative of a macroinvertebrate habitat with good water quality. Site 6 on the Usutu River had the highest SASS and ASPT scores, which are a clear reflection of the habitat quality of this river. In contrast, the relatively low SASS and ASPT scores at Site 4 on the Ngwavuma River are related to anthropogenic influences on this river. The river runs through extensive informal settlement areas and the town of Ingwavuma, with clear evidence of habitat disturbance all along the river.

There were marked differences in the SASS scores between the two sampling periods. All SASS parameters, i.e. SASS scores, number of taxa and ASPT scores, were notably higher during April 2013 (Table 4.6) compared to November 2012 (Table 4.5) at Sites 3 and 6. The number of taxa was considerably higher at all three sites during April 2013. During November 2012, SASS and ASPT scores ranged between 89-94 and 5.2-5.7, respectively, whereas during April 2013, the scores

ranged between 146-164 and 5.8-6.8. This is particularly true for Site 6 on the Usutu River, where the SASS and ASPT scores were considerably higher during April 2013. Only 16 taxa were recorded at Site 6 during November 2012, compared to 24 during April 2013. River flows were higher during April 2013 compared to November 2012, with higher river levels probably providing for more and greater variability in habitat availability for invertebrates. In addition, the November 2012 sampling survey was conducted shortly after a large flood release from the dam, after which the water levels receded quite rapidly, possibly causing a rapid decrease in habitat availability for aquatic invertebrates.

July 2013: The results of the SASS5 monitoring during July 2013 are presented in Table 4.7 and Figures 4.5-4.7. Highest SASS scores were recorded at Sites 1 and 2 on the Phongolo River below the dam, with these two sites showing notably higher SASS scores and number of taxa compared to all other sites. These high SASS scores are reflected in the high number of taxa recorded here, particularly at Site 2, where 30 taxa were recorded, which is markedly higher than at any other site. With the exception of Sites 1 and 2, SASS and ASPT scores and number of taxa were, however, lower at all other sites during July 2013 compared to April. This is particularly evident at Site 6 on the Usutu River, where the SASS score and number of taxa decreased from 164 and 24 in April to 116 and 18 in July, respectively. The high ASPT score at Site 3 during July is comparable to that recorded during April and although a relatively low number of taxa were recorded, most were relatively high-scoring sensitive taxa.

Table 4.5. Macroinvertebrate taxa recorded in the Phongolo and Usutu Rivers during November 2012. SASS5 and ASPT scores are given (1 = 1 individual, A = 2-10 individuals, B = 10-100 individuals).

Taxa	Sensitivity	Site 3	Site 6
Turbellaria	3	A	1
Oligochaeta	1	A	
Atyidae	8	A	A
Baetidae (2 sp.)	6	A	A
Baetidae (>2 sp.)	12		A
Caenidae	6	A	
Heptageniidae	13		A
Tricorythidae	9	1	
Coenagrionidae	4		A
Corduliidae	8		
Gomphidae	6		A
Libellulidae	4	1	1
Oligoneuridae	15		A
Belostomatidae	3		A
Corixidae	3	1	
Gerridae	5	A	
Naucoridae	7		A
Notonectidae	3	A	
Veliidae	5	1	
Hydropsychidae (1 sp.)	4	1	1
Hydroptilidae	6		
Leptoceridae	6	A	
Dytiscidae	5	1	
Elmidae	8		1
Helodidae	12		
Hydrophilidae	5	1	
Ceratopogonidae	5	1	
Chironomidae	2	A	1
Physidae	3	1	
Corbiculidae	5		
Lymnaeidae	3		
SASS score		**94**	**89**
No. of taxa		**18**	**16**
ASPT		**5.2**	**5.7**

Table 4.6. Macroinvertebrate data recorded in the Phongolo, Ngwavuma and Usutu Rivers during April 2013. SASS5 and ASPT scores are given (1 = 1 individual, A = 2-10 individuals, B = 10-100 individuals).

Taxon	Sensitivity	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Reference Site W4PONG-N2PON
Oligochaeta	1	B		A	A	A	A	A
Hirudinea	3			A	A	A		
Potamonautidae	3	A			A	A		
Atyidae	8	B	A	B		B	B	B
Palaemonidae	10						1	A
Hydracarina	8			1				
Perlidae	12							A
Baetidae (1 sp.)	4		B	A	A	A	B	
Baetidae (2 sp.)	6	B		B	B			B
Caenidae	6	A	B	B	A	A	A	A
Heptageniidae	13	A	A	B			A	B
Leptophlebiidae	9	B	B			B	1	A
Oligoneuridae	15		1	1			A	A
Polymitarcyidae	10							
Prosopistomatidae	15							A
Tricorythidae	9	1	1	1	1	1	1	A
Calopterygidae	10				A		1	
Chlorocyphidae	10					A		
Coenagrionidae	4	B	B	B	B	B	B	B
Corduliidae	8			1				A
Gomphidae	6	1	B	A	B	B	A	B
Libellulidae	4	B	A		B	B	B	A
Crambidae	12						B	
Belostomatidae	3	B	B	A	A	A	A	A
Corixidae*	3	1				1		
Gerridae*	5			A		A		
Hydrometridae	6			1		1	B	
Naucoridae*	7	A	A		1		1	A
Notonectidae	3	A				1		
Pleidae*	4							
Veliidae*	5	B		1	A	1	A	A
Hydropsychidae (1 sp.)	4		A	A				
Hydropsychidae (2 sp.)	6	B			B	B	B	A
Philopotamidae	10		A					
Leptoceridae	6	1	A	B	A	A	B	A
Dytiscidae	5	A		1		A	1	
Elmidae/Dryopidae	8			A			B	A
Gyrinidae	5			A		1		A
Haliplidae	5							A
Hydraenidae	8							
Hydrophilidae	5	1						
Limnichidae	8							A
Athericidae	13		A					
Ceratopogonidae	5							A

Table 4.6. continued.

Taxon	Sensitivity	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Reference Site W4PONG-N2PON
Chironomidae	2	B	A	B	A	A	1	A
Culicidae	1			1				
Simuliidae	5	1	1	1	1		A	
Tabanidae	5	A	A		A	A		
Tipulidae	5							A
Physidae	3	1	1					A
Planorbidae	3	A			A	A		A
Thiaridae	3	B	B		A			
Corbiculidae	5		1					
Sass score		**124**	**135**	**146**	**101**	**126**	**164**	**192**
No. of taxa		**25**	**21**	**25**	**21**	**25**	**24**	**30**
ASPT		**5.0**	**6.4**	**5.8**	**4.8**	**5.0**	**6.8**	**6.9**

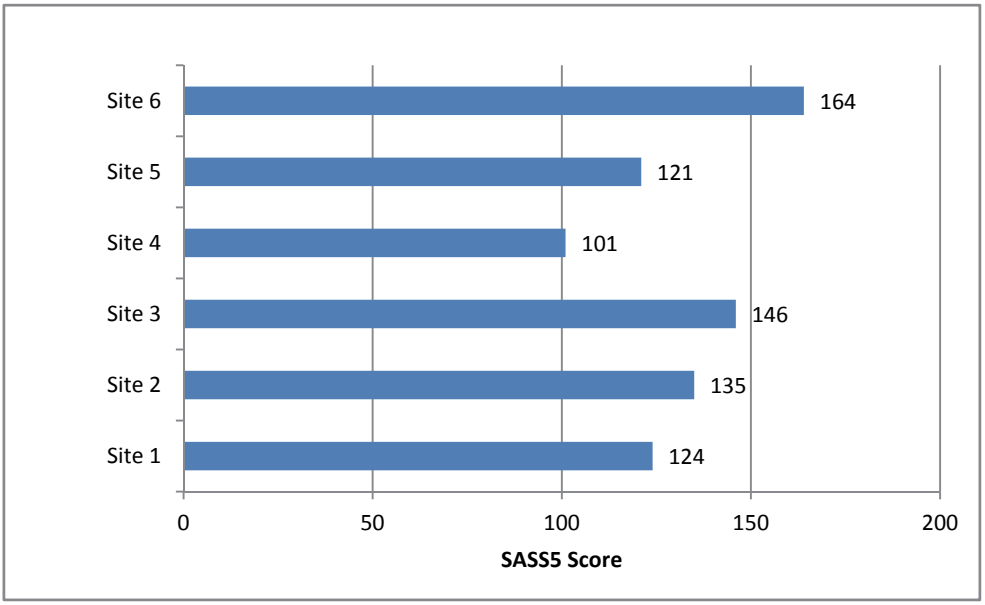


Figure 4.2. SASS5 scores recorded at seven sampling sites along the Phongolo, Ngwavuma and Usutu Rivers during April 2013.

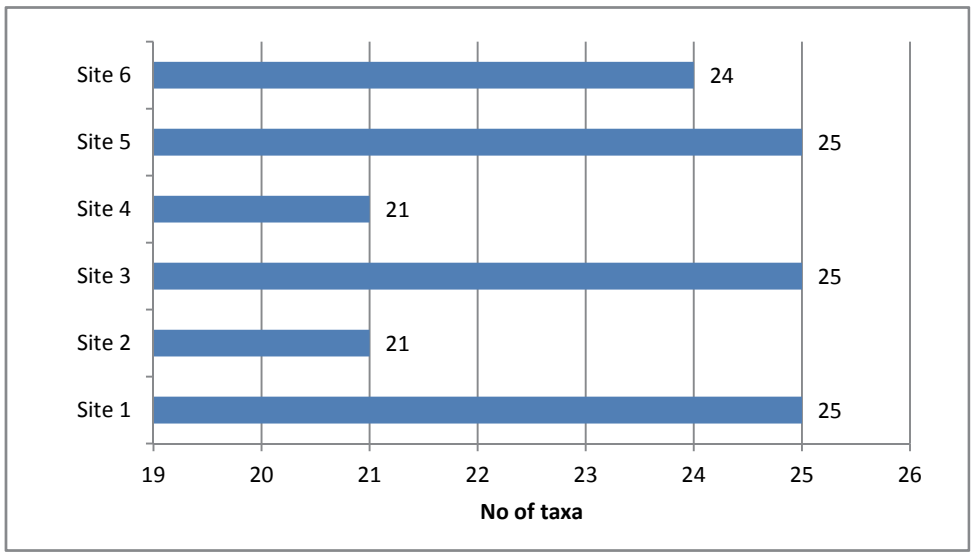


Figure 4.3. Number of macroinvertebrate taxa recorded at seven sampling sites along the Phongolo, Ngwavuma and Usutu Rivers during April 2013.

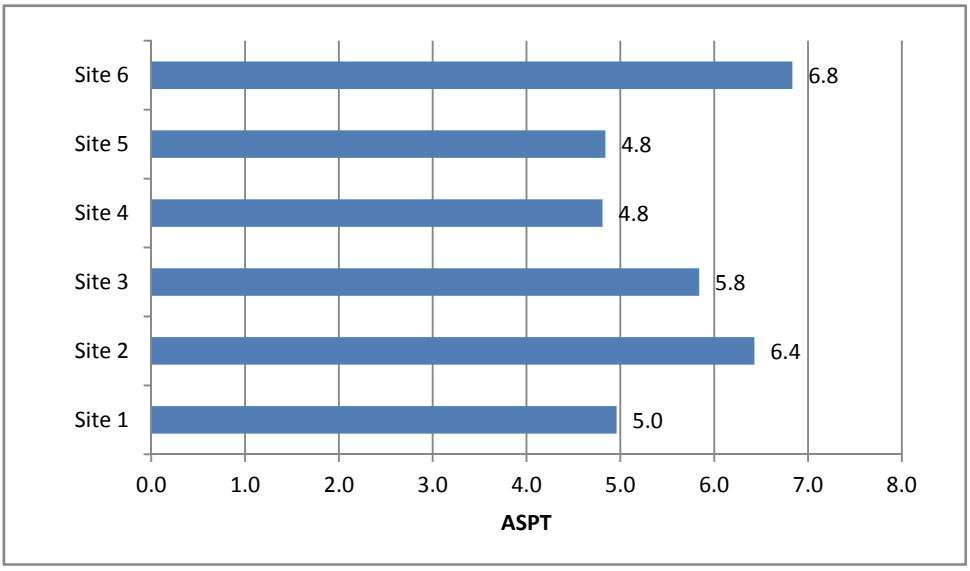


Figure 4.4. ASPT scores recorded at seven sampling sites along the Phongolo, Ngwavuma and Usutu Rivers during April 2013.

Table 4.7. Macroinvertebrate data recorded in the Phongolo, Ngwavuma and Usutu Rivers during July 2013. SASS5 and ASPT scores are given (1 = 1 individual, A = 2-10 individuals, B = 10-100 individuals).

Taxon	Sensitivity	Site 1	Site 2	Site 3	Site 4a	Site 4	Site 5	Site 6	Reference Site W4PONG-N2PON
Turbellaria	3	B	B						
Oligochaeta	1	A	A	B	1	A	B	1	A
Hirudinea	3						1	1	
Potamonautidae	3				1	A			
Atyidae	8	B	B	B			A	A	
Perlidae	12								A
Baetidae 2 sp	6	B	B		A	A	A	A	A
Baetidae> 2 sp	12			A	B	B	A	B	
Caenidae	6	1	B		1				A
Ephemeridae	15			B					
Heptageniidae	13	B	A					A	A
Leptophlebiidae	9				1				A
Tricorythidae	9								A
Calopterygidae	10					B			
Chlorocyphidae	10		A	A			B		
Synlestidae	8	A	B		B	A			
Coenagrionidae	4	A	A	B			A	A	A
Lestidae	8			A					
Platycnemididae	10								A
Aeshnidae	8	A	B		B				
Corduliidae	8	1	A						
Gomphidae	6			A		1	A	B	A
Libellulidae	4	B	B	A	B	B	B		A
Crambidae	12	B	A						
Corixidae	3			A				A	A
Gerridae	5						A		A
Hydrometridae	6		A						
Naucoridae	7	A	A	B	1	A	A	A	A
Nepidae	3								
Notonectidae	3	A		A			A		A
Pleidae	4					1			
Veliidae	5	A	A		A	1	A	A	A
Ecnomidae	8		A	A			1		
Hydropsychidae 2 sp	6		B		B	A		1	B
Hydropsychidae>2 sp	12						B		
Psychomyiidae	8		A					A	
Hydroptilidae	6		A		A				A
Leptoceridae	6		A					A	A
Poeciliidae	10	1							
Dytiscidae	5								A
Elmidae/Dryopidae	8	A	A	A	1			1	A
Gyrinidae	5	A				1	1		
Hydrophilidae	5				A				
Ceratopogonidae	5	A	A	A				A	A

Table 4.7. (continued)

Taxon	Sensitivity	Site 1	Site 2	Site 3	Site 4a	Site 4	Site 5	Site 6	Reference Site W4PONG-N2PON
Chironomidae	2	B	A	1	A	B	A	A	A
Culicidae	1				1	A			A
Simuliidae	5	A	A		A	A			A
Tabanidae	5	A	1		A	A	A		A
Tipulidae	5								A
Ancylidae	6		1						
Physidae	3	B	1						
Planorbidae	3								A
Thiaridae	3	B	B		A	A			A
Corbiculidae	5								
Sphaeriidae	3	1							A
Unionidae	6								
Sass score		**158**	**193**	**128**	**110**	**93**	**106**	**108**	**154**
No. of taxa		**26**	**30**	**18**	**20**	**18**	**18**	**17**	**29**
ASPT		**6.1**	**6.4**	**6.4**	**5.5**	**5.2**	**5.9**	**6.1**	**5.6**

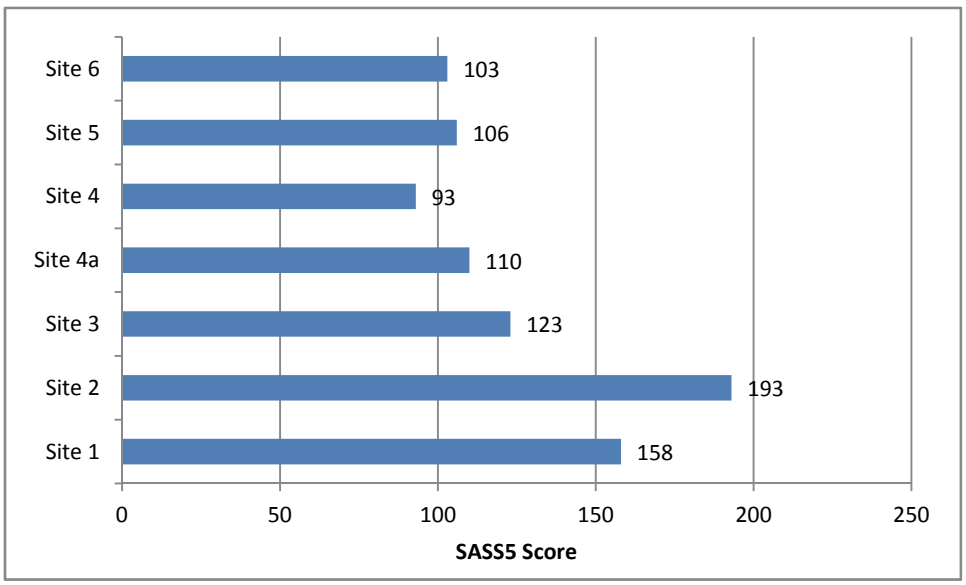


Figure 4.5. SASS5 scores recorded in the Phongolo, Ngwavuma and Usutu Rivers during July 2013.

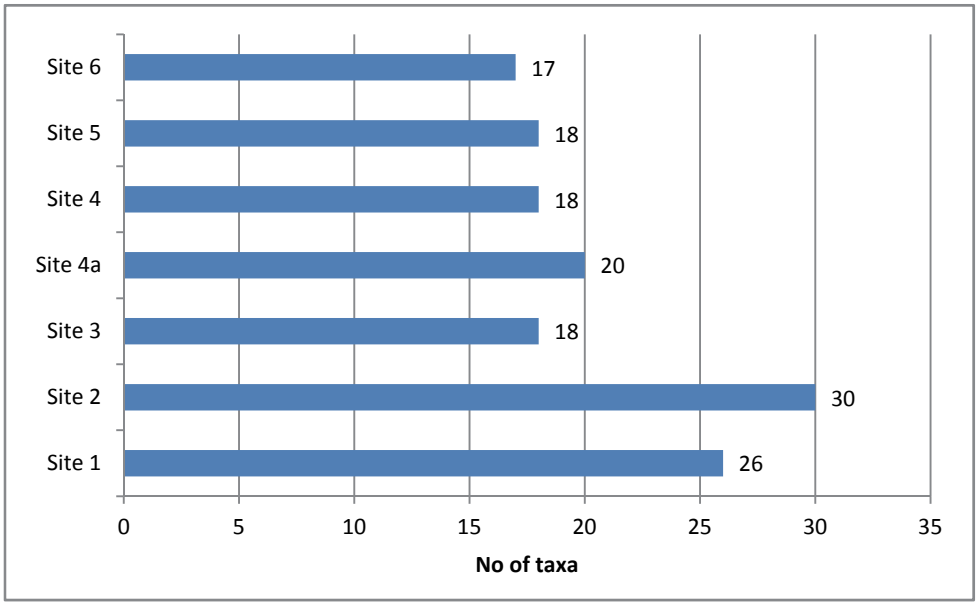


Figure 4.6. Number of taxa recorded in the Phongolo, Ngwavuma and Usutu Rivers during July 2013.

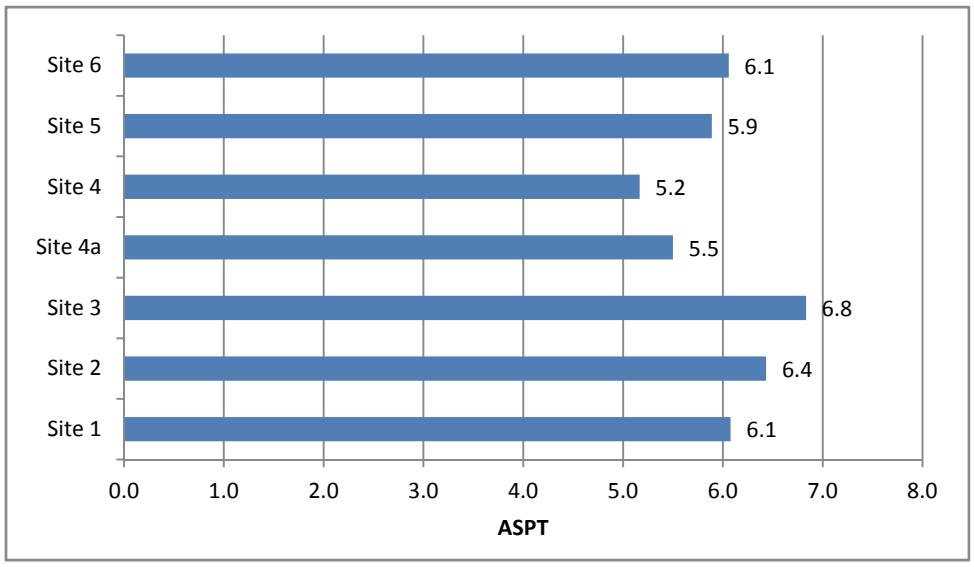


Figure 4.7. ASPT scores recorded in the Phongolo, Ngwavuma and Usutu Rivers during July 2013.

SASS and ASPT scores recorded during this study were plotted against known scores for Lowveld (Lower) sites (Dallas 2007), as a relative indicator of intra- and inter-site variability. SASS results for sampling sites in the Lower Phongolo, Ngwavuma and Usutu rivers during the study period fell well within the range for Lowveld SASS samples (Fig 4.8). It is important to note that the reference data for April and July (RHP W4PONG-N2PON) scored relatively high, not only within the current data set but also within the overall Lowveld ecoregion data set, with high flow reference data (April) coinciding with relatively high scores. This increases the confidence with which changes in the

macro-invertebrate community in the study area can be interpreted, based on the selected reference samples. It should however be noted that the reference site lies in the Lowveld Lower ecoregion, while Sites 1, 4a and 4 are located in the Lebombo Uplands ecoregion. As a result, scores at Sites 1, 4a and 4 could be slightly overestimated. Sites 2 and 3 (Phongolo River) and Site 6 (Usutu River) during April and July consistently had the highest ASPT and SASS scores. In contrast, the November 2012 samples from Site 3 and 6 had much lower scores. The reason for the relatively low scores during November is not clear, although sampling occurred shortly after a large flood release from the dam which resulted in very strong flows. At the lower end of the scale, sites in the Ngwavuma River, notably Site 4, has consistently low scores. The relatively high ASPT and SASS scores at Site 2, particularly during low flow conditions, are noteworthy. These high scores would suggest relatively good water and habitat quality at this site, even though this section of the river is characterised by modified/unnatural flows as a result of the dam. This would seem to indicate that the water release regime used for the dam creates flow and habitat conditions conducive to a relatively healthy invertebrate community, notably at Site 2.

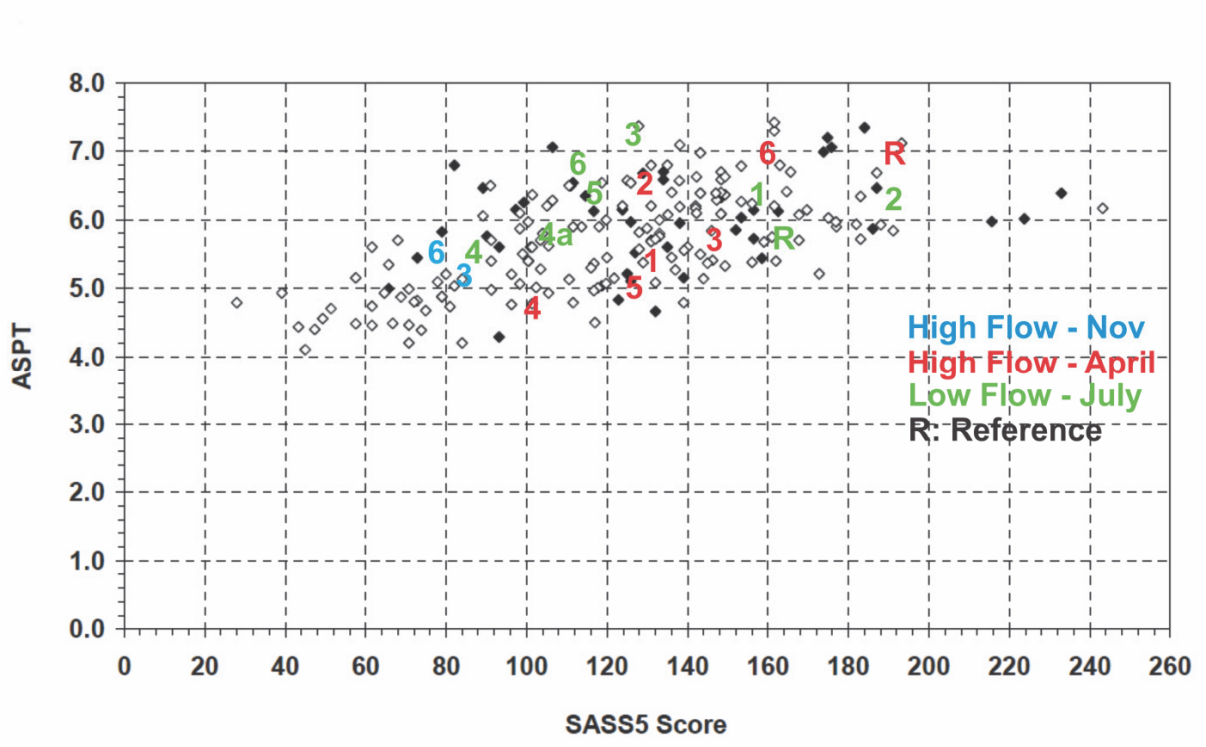


Figure 4.8. ASPT vs. SASS scores recorded during November 2012, April 2013 and July 2013 plotted against SASS5 data for the Lowveld (Lower) Ecoregion.

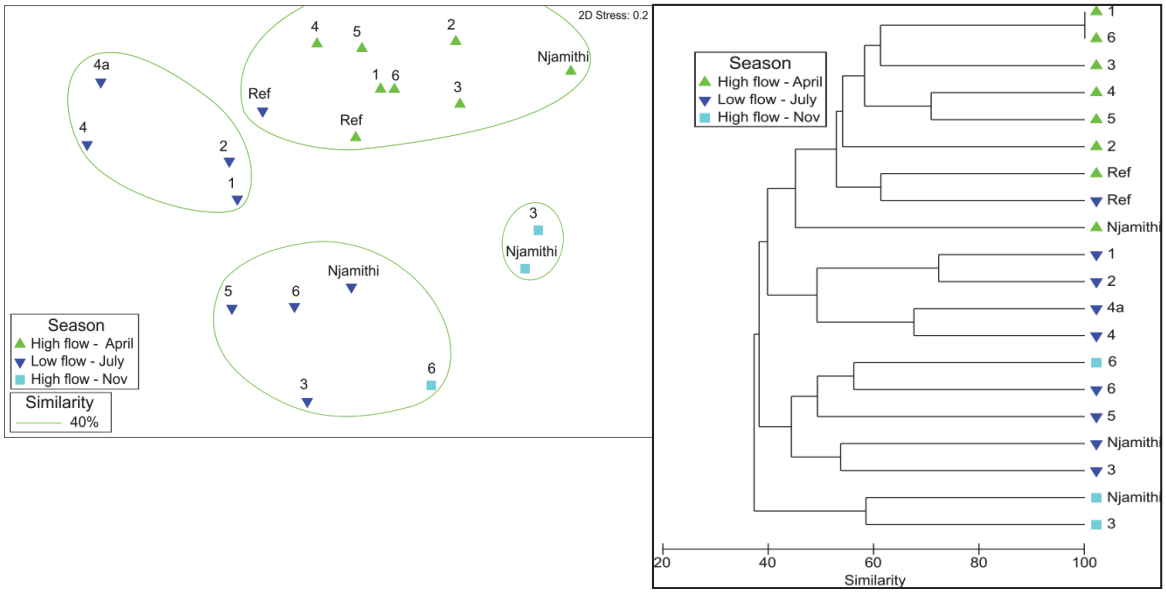


Figure 4.9. Cluster and MDS plots of the SASS data recorded during November 2012, April 2013 and July 2013 in the Phongolo River system (N = November 2012, A = April 2013, J = July 2013)

At a similarity level of 40%, the macroinvertebrate community showed a strong separation between sampling seasons (Figure 4.9). High-flow samples from April formed one group, low-flow samples (July) formed two distinct groups, while the November samples from Sites 3 formed a fourth group. The high- and low-flow reference samples were very similar, indicating that there was relatively little change in the reference community between high- and low-flow seasons. The relative proximity of the April high-flow samples from Sites 1, 2 and 3 on the Phongolo River to the reference sample on the MDS plot is an indication that the macroinvertebrate community observed in high-flow samples was relatively similar to that of the reference site, suggesting relatively little change from the reference condition. Similarly, during low-flow conditions in July, the Sites 1 and 2 communities showed a high similarity to the low-flow reference sample, suggesting relatively little change from the reference condition. These results suggest that flows released from the impoundment into the Lower Phongolo River result in macroinvertebrate communities which are quite similar to the reference community during high and low flows. In contrast, the Site 3 sample during low-flow conditions in July showed a relatively significant change from the reference condition. In this regard it should be noted that Site 3 is located on a small side-channel of the Phongolo River, with very low flow during the dry season. As such, Site 3 perhaps does not reflect the conditions in the main river channel and is not an ideal sampling site for the Phongolo River.

The Macroinvertebrate response assessment index (MIRAI)

The MIRAI results for high-flow (April) and low-flow (July) conditions for each metric group and the overall ecological category (EC) score and category are presented in Table 4.8 and Table 4.9, respectively. Table 4.10 presents the overall EC scores for all high-flow and low-flow samples.

At all sampling sites and during both sampling periods the EC categories ranged from C (moderately modified) to D (largely modified). Under high-flow conditions in April, the EC scores ranged from 47.4 at Site 4 (Ngwavuma River) to 65.9 at Site 6 on the Usutu River. During low-flow conditions, the EC scores ranged from 48.3 at Site 5 to 62.6 at Site 2 on the Phongolo River. The relatively high scores at Site 2 under both high- and low-flow conditions, compared to Site 1, are due to a combination of higher diversity of biotopes and good water quality. The consistently low scores in the Ngwavuma River are related to the poor water quality and modified habitat. In the Ngwavuma River, the relatively high score of 61.3 at Site 4a in July, compared to the rest of the Ngwavuma samples, is indicative of the generally good water quality and habitat diversity at the site. In contrast, the relatively low scores at Site 4, which is located downstream of Ingwavuma, reflects the extensive habitat disturbance and poor water quality caused by domestic and construction activities.

The distribution of the MIRAI EC scores shows a close resemblance to the distribution of the SASS vs ASPT scores plotted against historical data from the Lowveld Lower ecoregion (Fig. 4.8). Even though the SASS vs ASPT scores plot are merely an indication of how high or low the present scores were relative to historical data, it does provide some indication of the status of the macroinvertebrate community within a particular river reach.

Table 4.8. MIRAI scores for sampling sites along the Phongolo, Ngwavuma and Usutu Rivers for each metric group and the overall EC score and category during high-flow conditions in April 2013.

PON 1 - Phongolo River: High Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC	%WEIGHT FOR METRIC	COMMENTS
FLOW MODIFICATION	FM	40.0	*0.357*	14.2857	1	100	Regulated flows, unnatural (modified) flows from dam
HABITAT	H	57.8	*0.250*	14.4545	2	70	Scoured habitat, no sediment deposition, no sand and mud
WATER QUALITY	WQ	46.7	*0.179*	8.33333	4	50	Water clear, low conductivity, ASPT scores low
CONNECTIVITY & SEASONALITY	CS	48.8	*0.214*	10.4622	3	60	Simulated flows from seasonal dam releases, migration blocked
						280	
INVERTEBRATE EC				47.5358			
INVERTEBRATE EC CATEGORY				D			

PON 2 - Phongolo River: High Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC	%WEIGHT FOR METRIC	COMMENTS
FLOW MODIFICATION	FM	55.3	*0.357*	19.74	1	100	Flows regulated by dam
HABITAT	H	61.5	*0.250*	15.38	2	70	Generally good, All biotes available
WATER QUALITY	WQ	67.9	*0.179*	12.12	4	50	Water quality good, little algae, low conductivity
CONNECTIVITY & SEASONALITY	CS	60.0	*0.214*	12.86	3	60	Dam upstream, natural varibility reduced
						280	
INVERTEBRATE EC				60.1			
INVERTEBRATE EC CATEGORY				C/D			

PON 3 - Phongolo River: High Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	52.2	*0.30*	15.65	2	90	Flow regulated by dam releases, not main river channel
HABITAT	H	63.1	*0.20*	12.61	3	60	Very muddy, little SIC and SOOC
WATER QUALITY	WQ	64.1	*0.33*	21.38	1	100	Water quality good, low conductivity
CONNECTIVITY & SEASONALITY	CS	69.5	*0.17*	11.58	4	50	Flow regulated by dam, natural flow variability limited
						300	
INVERTEBRATE EC				61.2			
INVERTEBRATE EC CATEGORY				C/D			

PON 4 - Ngwavuma River: High Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	43.4	*0.300*	13.03	2	90	No weirs or dams, flow largely natural, but abstraction common
HABITAT	H	58.4	*0.200*	11.68	3	60	All biotopes, but site modified by sandwinning and construction
WATER QUALITY	WQ	28.2	*0.333*	9.39	1	100	Water whitish, domestic and construction activities around
CONNECTIVITY & SEASONALITY	CS	80.0	*0.167*	13.33	4	50	Flow natural, but abstraction for agricultural and domestic use
						300	
INVERTEBRATE EC				47.4			
INVERTEBRATE EC CATEGORY				D			

Table 4.8. (continued)

PON 5 - Ngwavuma River: High Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	46.7	*0.30*	14.00	2	90	Flow modified locally by culvert under road
HABITAT	H	64.3	*0.20*	12.86	3	60	Habitat at site largely unnatural due to road culvert.
WATER QUALITY	WQ	36.3	*0.33*	12.09	1	100	Water muddy, high conductivity
CONNECTIVITY & SEASONALITY	CS	80.0	*0.17*	13.33	4	50	Simulated flows from seasonal dam releases, migration blocked
						300	
INVERTEBRATE EC				52.3			
INVERTEBRATE EC CATEGORY				D			

PON 6 - Usuthu River: Low Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	50.4	*0.38*	19.39	1	100	Flow largely natural, some upstream abstraction and dams
HABITAT	H	56.8	*0.35*	19.67	3	90	Wide sandy wih limited SIC and SOOC
WATER QUALITY	WQ	68.1	*0.08*	5.24	3	20	Good, low conductivity
CONNECTIVITY & SEASONALITY	CS	88.8	*0.19*	17.08	4	50	Dams far upstream, flow seasonal
						260	
INVERTEBRATE EC				61.38			
INVERTEBRATE EC CATEGORY				C/D			

Table 4.9. MIRAI scores for sampling sites along the Phongolo, Ngwavuma and Usutu Rivers for each metric group and the overall EC score and category during low-flow conditions in July 2013.

PON 1 - Phongolo River: Low Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	52.7	*0.40*	21.09	1	100	Regulated unseasonally high flows from dam
HABITAT	H	52.3	*0.32*	16.75	2	80	Scoured habitat, no sediment deposition, no sand and mud
WATER QUALITY	WQ	86.5	*0.08*	6.92	4	20	Good, water clear, low conductivity
CONNECTIVITY & SEASONALITY	CS	48.8	*0.20*	9.76	3	50	Simulated flows, no natural variability, migration blocked
						250	
INVERTEBRATE EC				54.52			
INVERTEBRATE EC CATEGORY				D			

PON 2 - Phongolo River: Low Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	68.5	*0.40*	27.40	1	100	Regulated flows, unseasonal high flows
HABITAT	H	64.1	*0.32*	20.52	2	80	All biotes available
WATER QUALITY	WQ	61.5	*0.08*	4.92	4	20	Water quality good, little algae, low conductivity
CONNECTIVITY & SEASONALITY	CS	48.8	*0.20*	9.76	3	50	Dam upstream, natural varibility reduced
						250	
INVERTEBRATE EC				62.61			
INVERTEBRATE EC CATEGORY				C			

PON 3 - Phongolo River: Low Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	49.6	*0.38*	19.08	1	100	Flow regulated by dam, flow very low, not main river channel
HABITAT	H	44.8	*0.35*	15.50	2	90	Very muddy, little SIC and SOOC
WATER QUALITY	WQ	64.1	*0.08*	4.93	4	20	Water quality good, low conductivity
CONNECTIVITY & SEASONALITY	CS	60.0	*0.19*	11.54	3	50	Flow regulated by dam, natural flow variability limited
						260	
INVERTEBRATE EC				51.05			
INVERTEBRATE EC CATEGORY				D			

PON 4a - Ngwavuma River: Low Flow (upstream of Ngwavuwa Town)							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	57.5	*0.40*	22.99	3	100	Flow largely natural, no known dams, but some abstraction
HABITAT	H	55.0	*0.32*	17.59	2	80	All biotopes present
WATER QUALITY	WQ	59.5	*0.08*	4.76	1	20	Good, although relatively high conductivity
CONNECTIVITY & SEASONALITY	CS	80.0	*0.20*	16.00	4	50	Flow natural, no known weirs, migration natural
						250	
INVERTEBRATE EC				61.34			
INVERTEBRATE EC CATEGORY				C/D			

PON 4 - Ngwavuma River: Low Flow (downstream of Ngwavuma Town) (Reference Site)							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	42.0	*0.40*	16.79	3	100	No weirs or dams, flow largely natural, but abstraction common
HABITAT	H	50.3	*0.32*	16.10	2	80	All biotopes, but site modified by sandwinning and construction
WATER QUALITY	WQ	48.0	*0.08*	3.84	1	20	Water whitish, domestic and construction activities around
CONNECTIVITY & SEASONALITY	CS	60.0	*0.20*	12.00	4	50	Flow natural, but water abstraction for agricultural and domestic use
						250	
INVERTEBRATE EC				48.72			
INVERTEBRATE EC CATEGORY				D			

PON 5 - Ngwavuma River: Low Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	46.9	*0.40*	18.78	3	100	Flow modified locally by culvert under road
HABITAT	H	48.6	*0.32*	15.56	2	80	Habitat at site largely unnatural due to road culvert.
WATER QUALITY	WQ	53.2	*0.08*	4.26	1	20	Water muddy, high conductivity
CONNECTIVITY & SEASONALITY	CS	48.8	*0.20*	9.76	4	50	Simulated flows from seasonal dam releases, migration blocked
						250	
INVERTEBRATE EC				48.36			
INVERTEBRATE EC CATEGORY				D			

PON 6 - Usuthu River: Low Flow							
INVERTEBRATE EC METRIC GROUP		METRIC GROUP CALCULATED SCORE	CALCULATED WEIGHT	WEIGHTED SCORE OF GROUP	RANK OF METRIC GROUP	%WEIGHT FOR METRIC GROUP	COMMENTS
FLOW MODIFICATION	FM	50.4	*0.38*	19.39	1	100	Flow largely natural, some upstream abstraction and dams
HABITAT	H	56.8	*0.35*	19.67	3	90	Wide sandy wih limited SIC and SOOC
WATER QUALITY	WQ	68.1	*0.08*	5.24	3	20	Good, low conductivity
CONNECTIVITY & SEASONALITY	CS	88.8	*0.19*	17.08	4	50	Dams far upstream, flow seasonal
						260	
INVERTEBRATE EC				61.38			
INVERTEBRATE EC CATEGORY				C/D			

Table 4.10. The calculated MIRAI scores of the sites in the Phongolo River system under high-flow (April) and low-flow (July) conditions.

Site number	River	High-flow calculated score	High-flow ecological category	Low-flow calculated score	Low-flow ecological category
1	Phongolo	47.5	D	54.1	D
2	Phongolo	60.1	C/D	62.6	C
3	Phongolo	61.2	C/D	51.1	D
4a	Ngwavuma			61.3	C/D
4	Ngwavuma	47.4	D	48.7	D
5	Ngwavuma	52.4	D	48.3	D
6	Usutu	65.9	C	61.4	C/D

4.4.5 Riparian vegetation

The riparian vegetation of all the sites assessed, the description of the sites with regard to the diversity of the riparian vegetation, as well as the substrate composition and the assessed disturbance in the riparian zone are shown in Table 4.11.

The calculated VEGRAI scores (Table 4.12) show that the lowest scores were recorded at Sites 1, 2 and 4. These scores place Sites 1 and 4 in an Ecological Category D/E which indicates that these sites are in the lower range of an Ecological Category D. Kleynhans et al. (2007b) describe this category as "largely modified and where a large loss of natural habitat, biota and basic ecosystem functions has occurred". Although Site 2 was classified in the same category the slightly higher VEGRAI score of 49.4 indicates that the riparian vegetation was in a better condition. The scores obtained at Site 3 (Table 4.12), which is within the Ndumo Game Reserve, show the general downstream improvement of the riparian vegetation along the Phongolo River. It is of note that the riparian vegetation with the lowest impact is the upstream site on the Ngwavuma River, Site 4a, and the site on the Usutu River, Site 6.

Table 4.11. Site description of the riparian zones at Sites 1, 2, 3, 4a, 4, 5 and 6.

SITE DESCRIPTION			
Site details			
River:	**PHONGOLO**	Site no.	**Phongolo 1**
Site description			
Channel type	**Anabranched**	Substrate types in riparian zone (**dominant in bold**)	**Gravel/sand** Soil Rock/cobble
Extent of disturbance	**High**	Disturbances	**Flow regulation and released floods** **Access roads**
Percentage vegetation cover		**Trees : 51-75%** **Shrubs : 6-25%** **Sedges : 1-5%** **Grass : 1-5%**	
Riparian vegetation recorded			
Woody species		*Phyllanthus reticulatus*	
Vachellia robusta		*Syzygium guineense*	
Vachellia xanthophloea		*Trichilia emetica*	
Breonadia salicina		*Ziziphus mucronata*	
Croton megalobotrys			
Dichrostachys cinerea (terrestrial)		**Non-woody species recorded**	
Euclea natalensis		*Phragmites* spp.	
Ficus ingens		*Sesbania sesban*	
Ficus sycomorus		Sedge spp.	
Grewia flava		*Chromolaena odorata* (alien invasive)	
Grewia occidentalis			

Table 4.11. (continued)

SITE DESCRIPTION			
Site details			
River:	**PHONGOLO**	Site no.	**Phongolo 2**
Site description			
Channel type	**Anabranched**	Substrate types in riparian zone (**dominant in bold**)	Gravel/**sand** Soil **Sediment**
Extent of disturbance	**Medium to High**	Disturbances	**Flow regulation and released floods** **Access roads**
Percentage vegetation cover		**Trees : 76-100%** **Shrubs : 26-50%** **Reeds and sedges : 1-5%** **Bare ground and patches of grass : 5%**	
Riparian vegetation recorded			
Woody species		*Celtis africana*	
Vachellia ataxacantha		*Grewia flava*	
Vachellia robusta		*Breonadia salicina*	
Vachellia xanthophloea		*Gymnosporia* spp.	
Melia azedarach (alien invasive)		*Trichilia emetica*	
Ziziphus mucronata			
Sesbania punicea (alien invasive)		**Non-woody species recorded**	
Lantana camara (alien invasive)		*Phragmites* spp.	
Ficus sycomorus		*Sesbania sesban*	
Grewia occidentalis		*Chromolaena odorata* (alien invasive)	
Dichrostachys cinerea (terrestrial)		Sedge spp.	

SITE DESCRIPTION			
Site details			
River:	**PHONGOLO**	Site no.	**Phongolo 3**
Site description			
Channel type	**Anabranched**	Substrate types in riparian zone (**dominant in bold**)	**Sediment** Soil Gravel/sand
Extent of disturbance	**Medium to High**	Disturbances	**Flow regulation and released floods**
Percentage vegetation cover		**Trees : 76-100%** **Shrubs : 26-50%** **Sedges : 1-5%** **Grasses: 1-5 %**	
Riparian vegetation recorded			
Woody species		*Psidium guajava* (alien invasive)	
Vachellia xanthophloea		*Pleurostylia capensis*	
Antidesma venosum		*Rauvolfia caffra*	
Breonadia salicina		*Trichilia emetica*	
Chaetachme aristata		*Ziziphus mucronata*	
Ficus citrifolia			
Ficus sycomorus		**Non-woody species recorded**	
Kigelia africana		*Chromolaena odorata* (alien invasive)	
Phoenix reclinata		Sedge spp.	
Mangifera indica (alien)			

Table 4.11. (continued)

SITE DESCRIPTION			
Site details			
River:	**NGWAVUMA**	Site no	**Phongolo 4a**
Site description			
Channel type	**Single**	Substrate types in riparian zone (**dominant in bold**)	Gravel/**sand** Soil Bedrock
Extent of disturbance	**Medium**	Disturbances	**Road and bridge** **Grazing**
Percentage vegetation cover		**Trees : 51-75%** **Shrubs : 51-75%** **Reeds : 6-25%** **Sedges : 1-5%** **Bare ground/grass : 1-5%**	
Riparian vegetation recorded			
Woody species		*Melia azedarach* (alien invasive)	
Vachellia robusta		*Senna didymobotrya*	
Vachellia xanthophloea		*Syzygium cordatum*	
Breonadia salicina		*Trichilia emetica*	
Pechuel-loeschea leubnitziae			
Ficus ingens		**Non-woody species recorded**	
Ficus sycomorus		*Phragmites* spp.	
Grewia flava		*Sesbania sesban*	
Gymnosporia buxifolia		Sedge spp.	
		Nicotiana glauca (alien invasive)	

SITE DESCRIPTION			
Site details			
River:	**NGWAVUMA**	Site no	**Phongolo 4**
Site description			
Channel type	**Single**	Substrate types in riparian zone (**dominant in bold**)	Gravel/**sand** Soil Rock/cobble
Extent of disturbance	**Very high**	Disturbances	**Road and bridge** **Grazing**
Percentage vegetation cover		**Trees : 26-50%** **Shrubs : 51-75%** **Reeds : 26-50%** **Sedges : 1-5%** **Grasses : 26-50%**	
Riparian vegetation recorded			
Woody species		**Non-woody species recorded**	
Vachellia robusta		*Phragmites* spp.	
Vachellia xanthophloea		*Sesbania sesban*	
Ficus sycomorus		Sedge spp.	
Ficus citrifolia		*Nicotiana glauca* (alien invasive)	
Melia azedarach (alien invasive)		*Datura* spp. (alien invasive)	
Pechuel-loeschea leubnitziae		*Ricinus communis* (alien invasive)	
Sesbania punicea (alien invasive)			
Trichilia emetic			

Table 4.11. (continued)

SITE DESCRIPTION			
Site details			
River:	**NGWAVUMA**	Site no	**Phongolo 5**
Site description			
Channel type	**Single**	Substrate types in riparian zone (**dominant in bold**)	**Soil** **Gravel/sand** Sediment
Extent of disturbance	**Low to Medium**	Disturbances	**Flow regulation (low-water bridge acts as weir and the concentrated flow through the culverts causes excessive downstream erosion)** **Crop farming**
Percentage vegetation cover		**Trees : 76-100%** **Shrubs : 26-50%** **Reeds : 6-25%**	
Riparian vegetation recorded			
Woody species		*Lantana camara* (alien invasive)	
Vachellia ataxacantha		*Melia azedarach* (alien invasive)	
Vachellia xanthophloea		*Trichilia emetic*	
Breonadia salicina			
Dichrostachys cinerea (terrestrial)		**Non-woody species recorded**	
Diospyros lycioides		*Phragmites* spp.	
Ficus citrifolia		*Chromolaena odorata* (alien invasive)	
Ficus sycomorus		*Nicotiana glauca*	
Grewia flava			
Gymnosporia spp.			

SITE DESCRIPTION			
Site details			
River:	**USUTU**	Site no	**Phongolo 6**
Site description			
Channel type	**Single (there is evidence that the river can be braided in low flows)**	Substrate types in riparian zone (**dominant in bold**)	**Gravel/sand** Sediment Soil
Extent of disturbance	**Low**	Disturbances	**Flow** **Water quality**
Percentage vegetation cover		**Trees : 76-100%** **Shrubs : 6-25%** **Reeds: 26-50%** **Bare ground and grasses: 1-5%**	
Riparian vegetation recorded			
Woody species		*Grewia hexamita*	
Vachellia robusta		*Melia azedarach* (alien invasive)	
Vachellia tortilis		*Phyllanthus reticulates*	
Vachellia xanthophloea		*Trema orientalis*	
Bridelia micrantha		*Ziziphus mucronata*	
Dovyalis zeyheri			
Ficus citrifolia		**Non-woody species recorded**	
Ficus sycomorus		*Phragmites* spp.	
Grewia flavescens		Sedge spp.	

Table 4.12. The calculated VEGRAI scores of the sites in the Phongolo River system.

Site number	River	Calculated score	Ecological category
1	Phongolo	38.8	D/E
2	Phongolo	49.4	D
3	Phongolo	62.0	C/D
4a	Ngwavuma	82.0	B
4	Ngwavuma	41.3	D/E
5	Ngwavuma	58.8	C/D
6	Usutu	82.3	B

4.4.6 Fish

At the outset of this component of the report it should again be pointed out that the sites sampled in this study were situated in two geomorphological zones, namely the Lower Foothill and Lowland River zones (Rowntree et al., 2000). Each of these zones not only has characteristic alluvial material that forms the substrate but they also have a distinctive hydrology based on the gradient. Where a Lower Foothill zone characteristically has coarse-grained alluvial material, such as boulders and cobbles, the river bed in Lowland River zones is dominated by fine-grained alluvial material such as sand and silt. The water velocity in a Lower Foothill zone is generally higher than in the Lowland River zone. Based on the composition of the bed material, Sites 1, 2, and 4 were regarded to be in a Lower Foothill zone while Sites 3, 5, and 6 were in a Lowland River zone. Although Site 4a could be regarded as being in a Lower Foothill zone, the river bed is sand-dominated which could be an indication that it should rather be classified as a Lowland River.

Fish were sampled during all the surveys (Table 4.1) and, with the exception of Site 4 that was sampled twice and Site 4a that was sampled only once, all other sites were sampled three times. For the calculation of the FRAI scores the data of all the surveys at a site were combined.

Observed environmental conditions at the sites during the surveys

The environmental conditions observed during the surveys and scored according to the descriptions provided on the field form (Kleynhans, 2007) showed seasonal variation. In all surveys for Sites 3, 5 and 6 the water was turbid with flow ranging from “low” to “strong” with water clear and flow varying from “moderate to strong” for Sites 1, 2, 4a and 4 (Tables 4.13, 4.14 and 4.15).

Table 4.13. Summary of the observed environmental conditions at the sites during the fish surveys in August and November 2012.

	Site 2	Site 3	Site 5	Site 6
Observed conditions				
Turbidity	Clear	Very turbid	Moderate	Moderate
Colour	Brown tinge	Dark brown	Brown	Transparent brown
Flow	Moderate/low	Low	Moderate	Moderate
Comments		Difficult site – dominated by fast shallow and fast deep substrate = fallen logs and no coarse alluvial material	Flow is only recent – during August visit there was no flow	The water (deep) against the left-hand bank cannot be surveyed

Table 4.14. Summary of the observed environmental conditions at the sites during the fish surveys in April 2013.

	Site 1	Site 3	Site 4	Site 5	Site 6
Observed conditions					
Turbidity	Clear	Turbid	Clear	Turbid	Moderate
Colour	Green tinge	Brown	Brown tinge	Brown	Brown
Flow	Strong	Moderate	Moderate	Moderate	Strong
Comments	Flow removes all sediments		Algae observed on coarse alluvial material	Situation similar to August survey	Flow is into the reeds of the right-hand bank, increasing fish habitat

Table 4.15. Summary of the observed environmental conditions at the sites during the fish surveys in July 2013.

	Site 1	Site 2	Site 3	Site 4a	Site 4	Site 5	Site 6
Observed conditions							
Turbidity	Clear	Clear	Turbid	Clear	Clear	Turbid	Moderate
Colour	None	Blue-green tinge	Brown with green tinge	No colour	No colour	Brown	Brown
Flow	Moderate	Moderate	Very Low	Moderate	Moderate	Moderate	Moderate
Comments			Dead woody debris – fish habitat		High impact of brick works and car wash		

During each survey the flow-depth classes and available cover for fish were identified after which the abundance was rated and scored. The highest ratings recorded during all the surveys are shown in Table 4.16 (a-g) and this illustrates the availability of fish habitat and cover at the sites.

Table 4.16. The maximum abundance scores of the fish velocity-depth classes and cover present at the sites on the Phongolo River system (abundance: 1 = absent, 1 = rare; 2 = sparse; 3 = moderate; 4 = abundant; 5 = very abundant) (adapted from Kleynhans, 2007).

a)

Site number: 1

Velocity-depth class (habitat type)							
Type	Score	Type	Score	Type	Score	Type	Score
Slow-deep	2	Slow-shallow	5	Fast-deep	4	Fast-shallow	5
Cover							
Overhanging vegetation	3	Overhanging vegetation	3	Overhanging vegetation	0	Overhanging vegetation	2
Undercut banks and root wads	2	Undercut banks and root wads	1	Undercut banks and root wads	1	Undercut banks and root wads	1
Substrate	5	Substrate	5	Substrate	5	Substrate	5
Aquatic macrophytes	1	Aquatic macrophytes	2	Aquatic macrophytes	1	Aquatic macrophytes	1
Water column	3	Water column	1	Water column	4	Water column	1

b)

Site number: 2

Velocity-depth class							
Type	Score	Type	Score	Type	Score	Type	Score
Slow-deep	1	Slow-shallow	4	Fast-deep	5	Fast-shallow	5
Cover							
Overhanging vegetation	2	Overhanging vegetation	2	Overhanging vegetation	4	Overhanging vegetation	1
Undercut banks and root wads	4	Undercut banks and root wads	0	Undercut banks and root wads	1	Undercut banks and root wads	0
Substrate	5	Substrate	5	Substrate	5	Substrate	5
Aquatic macrophytes	0	Aquatic macrophytes	0	Aquatic macrophytes	3	Aquatic macrophytes	2
Water column	4	Water column	1	Water column	3	Water column	1

c)

Site number: 3

Velocity-depth class							
Type	Score	Type	Score	Type	Score	Type	Score
Slow-deep	5	Slow-shallow	5	Fast-deep	0	Fast-shallow	4
Cover							
Overhanging vegetation	4	Overhanging vegetation	4	Overhanging vegetation		Overhanging vegetation	2
Undercut banks and root wads	3	Undercut banks and root wads	3	Undercut banks and root wads		Undercut banks and root wads	2
Substrate	1	Substrate	2	Substrate		Substrate	2
Aquatic macrophytes	0	Aquatic macrophytes	1	Aquatic macrophytes		Aquatic macrophytes	0
Water column	3	Water column	1	Water column		Water column	1

d)

Site number: 4a

Velocity-depth class							
Type	Score	Type	Score	Type	Score	Type	Score
Slow-deep	3	Slow-shallow	4	Fast-deep	3	Fast-shallow	5
Cover							
Overhanging vegetation	4	Overhanging vegetation	2	Overhanging vegetation	2	Overhanging vegetation	5
Undercut banks and root wads	1	Undercut banks and root wads	0	Undercut banks and root wads	2	Undercut banks and root wads	0
Substrate	1	Substrate	1	Substrate	4	Substrate	2
Aquatic macrophytes	0	Aquatic macrophytes	0	Aquatic macrophytes	0	Aquatic macrophytes	0
Water column	3	Water column	1	Water column	3	Water column	0

Table 4.16. (continued)

e)

Site number: 4

Velocity-depth class							
Type	Score	Type	Score	Type	Score	Type	Score
Slow-deep	0	Slow-shallow	5	Fast-deep	1	Fast-shallow	4
Cover							
Overhanging vegetation		Overhanging vegetation	2	Overhanging vegetation	2	Overhanging vegetation	2
Undercut banks and root wads		Undercut banks and root wads	1	Undercut banks and root wads	1	Undercut banks and root wads	1
Substrate		Substrate	2	Substrate	3	Substrate	3
Aquatic macrophytes		Aquatic macrophytes	0	Aquatic macrophytes	0	Aquatic macrophytes	1
Water column		Water column	1	Water column	1	Water column	1

f)

Site number: 5

Velocity-depth class							
Type	Score	Type	Score	Type	Score	Type	Score
Slow-deep	3	Slow-shallow	5	Fast-deep	5	Fast-shallow	5
Cover							
Overhanging vegetation	3	Overhanging vegetation	2	Overhanging vegetation	2	Overhanging vegetation	2
Undercut banks and root wads	4	Undercut banks and root wads	2	Undercut banks and root wads	5	Undercut banks and root wads	2
Substrate	5	Substrate	5	Substrate	5	Substrate	4
Aquatic macrophytes	0	Aquatic macrophytes	0	Aquatic macrophytes	0	Aquatic macrophytes	0
Water column	4	Water column	1	Water column	4	Water column	1

g)

Site number: 6

Velocity-depth class							
Type	Score	Type	Score	Type	Score	Type	Score
Slow-deep	2	Slow-shallow	4	Fast-deep	2	Fast-shallow	4
Cover							
Overhanging vegetation	4	Overhanging vegetation	3	Overhanging vegetation	2	Overhanging vegetation	4
Undercut banks and root wads	1	Undercut banks and root wads	1	Undercut banks and root wads	1	Undercut banks and root wads	1
Substrate	1	Substrate	1	Substrate	1	Substrate	1
Aquatic macrophytes	0	Aquatic macrophytes	0	Aquatic macrophytes	0	Aquatic macrophytes	0
Water column	3	Water column	1	Water column	3	Water column	0

Fish diversity

Tables 4.17 to 4.20 show the species diversity observed during the surveys as well as the total diversity of each site. As can be expected, the lowest diversity, with the exception of the two sites immediately downstream of the impoundment, was observed at Site 4a which was the highest upstream site. In addition, it should be borne in mind that this site was only sampled once. The highest diversity was observed at Site 6.

Table 4.17. The fish diversity at sites located in the Lower Foothill Zone of the Phongolo River.

Families	Species	Site 1 April 2013	Site 1 July 2013	Site 1 Total	Site 2 August 2012	Site 2 April 2013	Site 2 July 2013	Site 2 Total
Gobiidae	*Glossogobius callidus*	x	x	**x**	x	x	x	**x**
	Glossogobius giuris	x	x	**x**	x	x	x	**x**
Anguillidae	*Anguilla marmorata*	x	x	**x**			x	**x**
Cyprinidae	*Labeobarbus marequensis*					x		**x**
	Barbus trimaculatus					x	x	**x**
	Barbus unitaeniatus						x	**x**
	Labeo cylindricus	x		**x**	x	x	x	**x**
	Labeo molybdinus	x		**x**				
Clariidae	*Clarias gariepinus*	x		**x**	x			**x**
Mochokidae	*Chiloglanis paratus*						x	**x**
	Synodontis zambezensis				x	x		**x**
Characidae	*Hydrocynus vittatus*	x		**x**	x	x		**x**
	Brycinus imberi						x	**x**
	Micralestes acutidens	x		**x**	x	x	x	**x**
Mormyridae	*Marcusenius macrolepidotus*							
Cichlidae	*Oreochromis mossambicus*		x	**x**	x	x	x	**x**
	Tilapia rendalli	x	x	**x**				
	Tilapia sparrmanii	x	x	**x**		x	x	**x**
	Pseudocrenilabrus philander	x	x	**x**				
Schilbeidae	*Schilbe intermedius*				x			**x**
Total		**11**	**7**	**12**	**9**	**10**	**11**	**16**

Table 4.18. Fish diversity observed at sites located in the Lower Foothill Zone of the Ngwavuma River.

Families	Species	Site 4a July 2013	Site 4 April 2013	Site 4 July 2013	Site 4 Total
Gobiidae	*Glossogobius callidus*		x		**x**
	Glossogobius giuris		x		**x**
	Barbus afrohamiltoni	**x**		x	**x**
	Barbus argenteus	**x**			
	Barbus paludinosus		x		**x**
	Barbus trimaculatus	**x**	x		**x**
	Barbus unitaeniatus	**x**	x	x	**x**
	Labeo cylindricus	**x**	x		**x**
	Labeo molybdinus	**x**		x	**x**
Clariidae	*Clarias gariepinus*	**x**	x	x	**x**
Mochokidae	*Chiloglanis paratus*	**x**	x	x	**x**
	Chiloglanis swierstrai	**x**			
Cichlidae	*Oreochromis mossambicus*	**x**	x	x	**x**
	Pseudocrenilabrus philander			x	**x**
Total		**10**	**9**	**7**	**12**

Table 4.19. Fish diversity observed at sites located in the Lowland River Zones of the main stem of the Phongolo River.

Families	Species	Site 3 Nov 2012	Site 3 April 2013	Site 3 July 2013	Site 3 Total
Gobiidae	*Awaous aeneofuscus*				
	Glossogobius callidus			X	**X**
	Glossogobius giuris				
	Redigobius dewaali				
Anguillidae	*Anguilla bicolor*				
	Anguilla bengalensis				
	Anguilla marmorata				
	Anguilla mossambica				
Cyprinidae	*Barbus afrohamiltoni*			X	**X**
	Barbus annectens				
	Barbus paludinosus	X		X	**X**
	Barbus radiatus				
	Barbus toppini	X			**X**
	Barbus trimaculatus				
	Barbus unitaeniatus		X	X	**X**
	Barbus viviparus				
	Labeo congoro				
	Labeo cylindricus	X		X	**X**
	Labeo molybdinus				
	Labeo rosae				
	Labeo ruddi				
	Mesobola brevianalis				
Clariidae	*Clarias gariepinus*	X		X	**X**
	Clarias ngamensis				
	Clarias theodorae				
Mochokidae	*Chiloglanis paratus*				
	Chiloglanis swierstrai				
	Synodontis zambezensis	X			**X**
Characidae	*Hydrocynus vittatus*				
	Brycinus imberi	X		X	**X**
	Micralestes acutidens			X	**X**
Mormyridae	*Marcusenius macrolepidotus*	X			**X**
	Petrocephalus wesselsi	X			**X**
Cichlidae	*Oreochromis mossambicus*	X		X	**X**
	Oreochromis placidus				
	Tilapia rendalli				
	Tilapia sparrmanii	X			**X**
	Pseudocrenilabrus philander				
Schilbeidae	*Schilbe intermedius*	X		X	**X**
Megalopidae	*Megalops cyprinoides*				
Total		11	1	10	**15**

Table 4.20. Fish diversity observed at the sites located in the Lowland River Zones of the Ngwavuma and Usutu Rivers.

Families	Species	Site 5 Nov 2012	Site 5 April 2013	Site 5 July 2013	Site 5 Total	Site 6 Nov 2012	Site 6 April 2013	Site 6 July 2013	Site 6 Total
Gobiidae	*Awaous aeneofuscus*	X			**X**		X		**X**
	Glossogobius callidus		X	X	**X**		X	X	**X**
	Glossogobius giuris						X		**X**
Cyprinidae	*Barbus afrohamiltoni*		X		**X**			X	**X**
	Barbus annectens	X			**X**				
	Barbus paludinosus		X	X	**X**	X			**X**
	Barbus radiatus						X	X	**X**
	Barbus toppini	X	X		**X**	X	X		**X**
	Barbus trimaculatus					X			**X**
	Barbus unitaeniatus		X	X	**X**		X	X	**X**
	Barbus viviparus	X			**X**	X			**X**
	Labeo cylindricus	X	X	X	**X**		X	X	**X**
Clariidae	*Clarias gariepinus*	X	X	X	**X**	X	X	X	**X**
Mochokidae	*Chiloglanis paratus*		X		**X**				
	Chiloglanis swierstrai							X	**X**
	Synodontis zambezensis		X		**X**				
Characidae	*Hydrocynus vittatus*							X	**X**
	Brycinus imberi						X	X	**X**
	Micralestes acutidens	X	X		**X**		X	X	**X**
Mormyridae	*Marcusenius macrolepidotus*						X		**X**
	Petrocephalus wesselsi						X		**X**
Cichlidae	*Oreochromis mossambicus*			X	**X**	X	X	X	**X**
	Oreochromis placidus						X		**X**
	Tilapia rendalli						X		**X**
	Tilapia sparrmanii	X			**X**	X			**X**
	Pseudocrenilabrus philander		X	X	**X**	X			**X**
Schilbeidae	*Schilbe intermedius*	X			**X**		X	X	**X**
Total		**9**	**11**	**7**	**17**	**8**	**16**	**12**	**24**

The fish response assessment index (FRAI)

At the outset it should be pointed out that each of the sites used in this study is regarded as representative of the river reach in which it is situated, as is prescribed for the use in the FRAI calculations by Kleynhans (2007). The expected fish diversity of four sites used in the River Health Programme (RHP) (Table 4.21) was used in this study to determine the frequency of occurrence (FROC) ratings for the sites. These RHP sites were selected because of their proximity to the study sites. In addition, the data of the surveys were pooled for the calculation of the FRAI scores.

The calculated FRAI scores (Table 4.22) show that the lowest scores were obtained at the two sites immediately downstream of the impoundment, Sites 1 and 2, with a downstream improvement along the main stem of the Phongolo River. The highest score and consequently the highest ecological category, was obtained at Site 6 on the Usutu River.

Table 4.21. The expected fish diversity of the two geomorphological zones of the Phongolo River in which the sites occurred (adapted from Kleynhans, 2007). (Code 3 species refers to species that should occur but have not been recorded recently).

RHP site code	W4 PONG-N2PON	W4 PONG-KOSIB	W5 USUT-ABERC	W4 NGWA-D1840
LATITUDE	-27.3975	-27.00924	-26.84430	-27.09817
LONGITUDE	31.85141	32.30366	32.20590	32.06905
TRIBUTARY	Phongolo	Phongolo	Usutu	Ngwavuma
ECOREGION	3.09	3.08	3.08	12.01
GEOMORPHORPHOLOGICAL ZONE	LOWLAND	LOWLAND	LOWLAND	LOWER FOOTHILLS
ALTITUDE (m amsl)	180	34	42	121
Awaous aeneofuscus		x	x	
Anguilla bicolor bicolor		x	x	
Anguilla labiata		x	x	
Anguilla marmorata	X	x	x	
Anguilla mossambica	X	x	x	X
Barbus afrohamiltoni		x	x	X
Barbus annectens		x	x	X
Brycinus imberi	X	x	x	X
Labeobarbus marequensis	X		x	
Barbus paludinosus	X	x	x	X
Barbus radiatus		x	x	X
Barbus toppini		x	x	X
Barbus trimaculatus	X	x	x	X
Barbus unitaeniatus	X		x	X
Barbus viviparus	X	x	x	X
Cyprinus carpio	X		x	
Clarias gariepinus	X	x	x	
Clarias ngamensis		x	x	
Chiloglanis paratus	X		x	
Chiloglanis swierstrai	X		x	X
Glossogobius callidus	X	x	x	X
Glossogobius giuris	X	x	x	
Hydrocynus vittatus	X	x	x	
Labeo congoro	X		x	X
Labeo cylindricus	X	x	x	X
Labeo molybdinus	X		x	X
Labeo rosae	X	x	x	X
Micralestes acutidens	X	x	x	
Mesobola brevianalis	X	x	x	X
Megalops cyprinoides		x	x	
Marcusenius macrolepidotus	X	x	x	
Oreochromis mossambicus	X	x	x	X
Oreochromis placidus				
Petrocephalus wesselsi		x	x	
Pseudocrenilabrus philander	X		x	X
Redigobius dewaali				
Schilbe intermedius	X	x	x	X
Synodontis zambezensis	X	x	x	
Tilapia rendalli	X		x	
Tilapia sparrmanii		x	x	

Table 4.22. The calculated FRAI scores of the sites on the Phongolo River system.

Site number	River	Calculated score	Ecological category
1	Phongolo	30.5	E
2	Phongolo	35.6	E
3	Phongolo	50.2	D
4a	Ngwavuma	50.2	D
4	Ngwavuma	50.0	D
5	Ngwavuma	44.4	D
6	Usutu	66.3	C

4.5 Discussion and recommendations

The modified suitable habitat in the rivers in the lowland reaches lowers the scores for the fish and macroinvertebrates and this may have a negative impact on the EcoStatus categories (Table 4.23). Water quality analysis was not conducted for this component of the project and only *in situ* parameters were recorded. The calculated EC scores (Level IV) are a summary of the fish response assessment index (FRAI), the macroinvertebrate response assessment index (MIRAI) and the riparian vegetation response assessment index (VEGRAI) (refer to Sections 4.4.4, 4.4.5 and 4.4.6 in this chapter). A summary of the EcoStatus for each of the six sites is listed in Tables 4.23-4.28.

4.5.1 Geomorphology and habitat

After the completion of the project it is clear that the study area is under threat of population increase and signs of a constant proliferation in numbers of people and new developments (houses and cultivation plots). This trend was observed during the course of the four years that the sites were visited. In general, the biggest threat is the removal of natural vegetation in the form of land clearing for cultivation and housing, increased grazing pressure, trampling, removal of wood for fuel and building material and exposure of soil that result in erosion. This is particularly evident in the riparian zones where erosion is a problem and bank stability is compromised. In addition, sand-mining at Site 2 is a matter of concern, as the river banks and alluvial deposits in the active channel of the Phongolo River are mined.

Brick-making activities on the banks of the Ngwavuma River have a negative impact on the river bank, resulting in increased siltation downstream. The recent construction of the water-abstraction point at Site 5 and the stream deviation is a problem in the lower parts of the Ngwavuma River. The abstraction point was constructed on the right-hand bank of the river and closed the channels in this section of the river. The water is diverted to the left-hand side of the system and this has resulted in increased erosion and siltation. A huge concern is the result of these changes during the next rainy season, as increased flows will flood the abstraction point and the bridge which can result in increased erosion at the site. This erosion and siltation will have a negative impact on the habitat for

macroinvertebrates and fish downstream, with some minor negative impacts on the instream vegetation.

4.5.2 *In situ* physicochemical conditions

In situ physicochemical water quality data recorded during the study revealed the effect of the Pongolapoort Dam on the downstream environment, with cold, low-nutrient, clear water recorded at Site 1 downstream of the dam, relative to Site 2. The colder low-nutrient water at Site 1 can be expected to influence fish and macroinvertebrate diversity. Extensive algal growth on the rocks at Site 2 is indicative of increased nutrient concentrations in the river downstream of the dam resulting from agricultural return flows and informal settlements.

Consistently higher electrical conductivities in the Ngwavuma River, upstream and downstream of the Ingwavuma settlement, suggest an increased electrolyte load, possibly due to agricultural activities in the section of Swaziland through which the Ngwavuma River flows. Electrical conductivity values and TDS concentrations in the Ngwavuma River were considerably higher than in the Phongolo and Usutu Rivers. Good water quality was recorded in the Usutu River, a major tributary of the Phongolo River which drains a large section of Swaziland, an area with considerable agricultural developments.

4.5.3 Macroinvertebrates

The macroinvertebrate community showed a strong separation between high- and low-flow sampling seasons at most sites in the system, most notably in the lower Ngwavuma, Phongolo and in the Usutu Rivers. The reference samples used in the study showed relatively similar species composition under high- and low-flow conditions, indicating that there was little change in the reference community between high- and low-flow seasons. In this regard, it should be noted that the relative similarity between the April high-flow samples collected at Sites 1, 2 and 3 and the reference sample suggests that the macroinvertebrate communities observed in high-flow samples were relatively similar to those of the reference site. These sites therefore showed relatively little change from the reference condition, which suggests that high-flow conditions in the river downstream of the dam maintained a healthy invertebrate community. During low-flow conditions in July, the Site 1 and 2 communities also showed a high similarity to the low-flow reference sample, suggesting relatively little change from the reference condition. These results suggest that flows released from the dam into the Lower Phongolo River result in macroinvertebrate communities which are quite similar to the reference community during high and low flows.

Despite the relative similarity between the reference community and the majority of macroinvertebrate samples collected during the study, the MIRAI EC for all sites ranged between C-D, which is cause for concern. Highest EC scores were consistently recorded at Site 2 on the Phongolo River and at Site 6 on the Usutu River, this despite the fact that Site 6 largely lacked well-developed instream stone habitat. The high- and low-flow EC scores at these, and other sites, were consistent, suggesting that low-flow conditions did not create conditions unsuitable for the majority of taxa.

Currently, Site 4 is the only RHP sampling site on the Lower Phongolo River, downstream of the town of Ingwavuma, even though it is not actively monitored. This site consistently recorded lowest SASS and ASPT scores due to the poor habitat and water quality. Although this site is easily accessible, consideration should perhaps be given to the selection of an alternative RHP reference site, such as Site 4a on the upper Ngwavuma River or Site 2 on the Phongolo River.

4.5.4 Riparian vegetation

The calculated VEGRAI scores (Table 4.12) show that the riparian vegetation of the reference site, Site 6, on the Usutu River had the highest classification and was therefore “largely natural with few modifications and a small change in natural habitats and biota have taken place but the ecosystem functions were essentially unchanged”. This ratifies the decision to use this as a reference site. The lowest rating in the Phongolo River, namely a D/E Ecological Category was recorded at Site 1 but the ratings show that a downstream improvement occurred in the riparian vegetation with a rating of a D and C/D at Sites 2 and 3, respectively. This indicates that the effect of the flood releases decreases as the water moves downstream. The fact that the rating for the upstream site on the Ngwavuma River, Site 4a, is higher than those downstream of the town of Ingwavuma and other human settlements, Sites 4 and 5, is an indication of the negative anthropogenic impacts on the riparian vegetation.

4.5.5 Fish

The FRAI scores calculated for the sites (Table 4.22), and in particular the fact that the highest rating was the C Ecological Category recorded at Site 6, show that the instream habitats were more severely impacted than the riparian vegetation. As in the case of the VEGRAI scores, the best rating was obtained at the reference site, Site 6. In addition, the sites on the Phongolo River closest to the high-flow releases, Site 1 and Site 2, were the most severely impacted and could only be rated as an E ecological category which indicates that the sites are “seriously modified with an associated

loss of natural habitat, biota and basic ecosystem functions that is extensive". As in the case of the riparian vegetation, a downstream improvement was observed in the Phongolo River. Although all three the sites sampled in the Ngwavuma River were classified as being in a D Ecological Category, it should be noted that the lower score obtained at Site 5, when compared to Site 4, indicates that a downstream deterioration in the instream habitat had occurred. This latter aspect is regarded, as an indication of the negative anthropogenic impacts on the river.

4.5.6 EcoStatus of the system – below Pongolapoort Dam

At the end of the project, it became clear from the analysis that the PES values indicate that the Phongolo River system is under threat. The impacts at Site 1 are mostly related to the modified (regulated) flow regime due to the management strategy of the water releases from Pongolapoort Dam. The change in temperature (bottom releases) seems to lower the fish diversity at the site and the EcoStatus (EC) class is E. Linked to the lower than expected temperature (under natural conditions) is the possible increase in ammonia and exposure over extended periods has lowered the fish diversity and therefore modified the community structure. The higher EC class (D) for the macroinvertebrates can be linked to the presence of flow-dependent species and the possible absence of nutrients (total nitrogen and phosphates). The flow regime modifications have had a negative impact on the riparian vegetation and the current EC class is D/E. As expected, the overall EC class is low (D/E) and some management actions must be implemented to increase the class to at least a D (suggested EC% of between 47% and 50%).

As at the previous site, the fish EC class at Site 2 is E and the diversity is mostly threatened by poor water quality and to a lesser extent the habitat related to flow depth classes. The increase in temperature at the site compared to Site 1 may be influential in the slight increase in the EC% from 30.5% at Site 1 to 35.6% at Site 2. When evaluating the EC class for the macroinvertebrates, an improvement observed in the EC% from 50.8% to 61.5% between Site 1 and 2 is encouraging. This resulted in an improvement to class C/D for the EcoStatus. The riparian vegetation also showed an improved EC% from 38.8% at Site 1 to 49.4% (EC class D) at Site 2. A concern, however, is the increased harvesting of the trees and shrubs at Site 2, as more people move into some of the vacant areas adjacent to the river and this may result in a decline in the EC class in the near future. Currently the cumulative EC class for Site 2 is a D, but continued sand-mining and wood harvesting can result in a decline.

The current EC class for Site 3 is D and this can be considered low for a site in a game reserve. One must take into consideration that the site lacked good biotope diversity for both fish and macroinvertebrates and this has had a negative impact on the diversity of these communities. The

fish EC class was D (50.2%) and represents a significant improvement compared to Site 2. The EC class of the macroinvertebrates was a Class D at 56.1% and is lower (61.5%) compared to Site 2. This can be ascribed to the low habitat diversity at this site. The riparian vegetation improved from 49.4% at Site 2 to 62% (EC class C/D) at this site and this is a direct result of the protection of the area from wood harvesting. Currently, the overall EC class for Site 3 is D, but the authors are of the opinion that it should be improved to a class C in future.

When taking into account the current impacts at Site 4 (Ngwavuma River), the EC class is better than expected. The EC class for the fish at Site 4 is D (50.1%), with the macroinvertebrate class at a D (48.1%) as well. In both instances the poor water quality and habitat modifications can be listed as the most important impacts on the community structure for the instream biota. The EC class for the riparian vegetation is D/E (41.3%) and this is due to the removal of trees and shrubs from the river banks. One can expect this to continue as more people are utilising the riparian vegetation for building material and heating. In addition, the erosion associated with stock trampling of the river banks and the sand-mining (brick-making at Site 4) will definitely lower the EC class for the vegetation in future.

For the downstream Ngwavuma River site (Site 5) the current EC class is D. The main impacts are the removal of vegetation in the immediate catchment and the recent infilling of the streambed for a water abstraction point. The EC class for fish at Site 5 is D, but the EC% is lower (44.4%) compared to Site 4. Apart from water quality, some modifications to the habitat can be listed as possible reasons for this lower score at Site 5. With regard to the macroinvertebrates, a higher EC% was recorded for Site 5 (50.3%) compared to Site 4 (48.1%). One can attribute this to a slight improvement in water quality related to the macroinvertebrates.

The last site monitored was on the Usutu River (Site 6). The fish diversity scored an EC class C (66.3%) and the macroinvertebrate EC class is C (63.7%). This can be related to the improved water quality compared to the other rivers. One must remember that the habitat diversity is low (absence of riffles) in the Usutu River. The EC class for the riparian vegetation at Site 6 is currently in a class B (82.3%), but encroachment from local communities on the left-hand bank may have a negative impact in future.

Table 4.23. Level IV EcoStatus results and ecological category of Site 1 on the Phongolo River.

INSTREAM BIOTA	Importance Score	Weight	EC %	EC
FISH				
1.What is the natural diversity of **fish** species with different flow requirements	1	100		
2.What is the natural diversity of **fish** species with a preference for different cover types	2	70		
3.What is the natural diversity of **fish** species with a preference for different flow depth classes	3	60		
4. What is the natural diversity of **fish** species with various tolerances to modified water quality	4	20		
FISH ECOLOGICAL CATEGORY	10	250	**30.5**	**E**
AQUATIC INVERTEBRATES				
1. What is the natural diversity of **invertebrate** biotopes	2	80		
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements	1	100		
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality	4	20		
AQUATIC INVERTEBRATE ECOLOGICAL CATEGORY	**7**	200	**50.8**	**D**
INSTREAM ECOLOGICAL CATEGORY (No confidence)		450	**41.3**	**D/E**

INSTREAM ECOLOGICAL CATEGORY WITH CONFIDENCE	Confidence rating	Proportions	Modified weights
Confidence rating for **fish** information	4	0.44	13.56
Confidence rating for **macroinvertebrate** information	5	0.56	28.22
	9	1.00	41.78
INSTREAM ECOLOGICAL CATEGORY	**EC**		**D/E**

RIPARIAN VEGETATION	EC %	EC
RIPARIAN VEGETATION ECOLOGICAL CATEGORY	**38.8**	**D/E**

ECOSTATUS	Confidence rating	Proportions	Modified weights
Confidence rating for instream biological information	4.55556	0.69	29.03
Confidence rating for riparian vegetation zone information	2	0.31	11.84
	6.55556	1.00	40.87
ECOSTATUS	**EC**		**D/E**

Table 4.24. Level IV EcoStatus results and ecological category of Site 2 on the Phongolo River.

INSTREAM BIOTA	Importance Score	Weight	EC %	EC
FISH				
1.What is the natural diversity of **fish** species with different flow requirements	1	100		
2.What is the natural diversity of **fish** species with a preference for different cover types	2	70		
3.What is the natural diversity of **fish** species with a preference for different flow depth classes	3	60		
4. What is the natural diversity of **fish** species with various tolerances to modified water quality	4	20		
FISH ECOLOGICAL CATEGORY	10	250	**35.6**	**E**
AQUATIC INVERTEBRATES				
1. What is the natural diversity of **invertebrate** biotopes	2	80		
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements	1	100		
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality	4	20		
AQUATIC INVERTEBRATE ECOLOGICAL CATEGORY	**7**	200	**61.5**	**C/D**
INSTREAM ECOLOGICAL CATEGORY (No confidence)		450	**49.4**	**D**

INSTREAM ECOLOGICAL CATEGORY WITH CONFIDENCE	Confidence rating	Proportions	Modified weights
Confidence rating for **fish** information	4	0.44	15.82
Confidence rating for **macroinvertebrate** information	5	0.56	34.17
	9	1.00	49.99
INSTREAM ECOLOGICAL CATEGORY	**EC**		**D**

RIPARIAN VEGETATION	EC %	EC
RIPARIAN VEGETATION ECOLOGICAL CATEGORY	**49.4**	**D**

ECOSTATUS	Confidence rating	Proportions	Modified weights
Confidence rating for instream biological information	4.55556	0.69	34.74
Confidence rating for riparian vegetation zone information	2	0.31	15.07
	6.55556	1.00	49.81
ECOSTATUS	**EC**		**D**

Table 4.25. Level IV EcoStatus results and ecological category of Site 3 on the Phongolo River.

INSTREAM BIOTA	Importance Score	Weight	EC %	EC
FISH				
1.What is the natural diversity of **fish** species with different flow requirements	1	100		
2.What is the natural diversity of **fish** species with a preference for different cover types	2	70		
3.What is the natural diversity of **fish** species with a preference for different flow depth classes	3	60		
4. What is the natural diversity of **fish** species with various tolerances to modified water quality	4	20		
FISH ECOLOGICAL CATEGORY	10	250	**50.2**	**D**
AQUATIC INVERTEBRATES				
1. What is the natural diversity of **invertebrate** biotopes	2	90		
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements	1	100		
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality	4	20		
AQUATIC INVERTEBRATE ECOLOGICAL CATEGORY	**7**	210	**56.1**	**D**
INSTREAM ECOLOGICAL CATEGORY		460	**53.3**	**D**

INSTREAM ECOLOGICAL CATEGORY WITH CONFIDENCE	Confidence rating	Proportions	Modified weights
Confidence rating for **fish** information	4	0.44	22.31
Confidence rating for **macroinvertebrate** information	5	0.56	31.17
	9	1.00	53.48
INSTREAM ECOLOGICAL CATEGORY	**EC**		**D**

RIPARIAN VEGETATION	EC %	EC
RIPARIAN VEGETATION ECOLOGICAL CATEGORY	**62.0**	**C/D**

ECOSTATUS	Confidence rating	Proportions	Modified weights
Confidence rating for instream biological information	4.55556	0.69	37.16
Confidence rating for riparian vegetation zone information	2	0.31	18.92
	6.55556	1.00	56.08
ECOSTATUS	**EC**		**D**

Table 4.26. Level IV EcoStatus results and ecological category of Site 4 on the Ngwavuma.

INSTREAM BIOTA	Importance Score	Weight	EC %	EC
FISH				
1.What is the natural diversity of **fish** species with different flow requirements	1	100		
2.What is the natural diversity of **fish** species with a preference for different cover types	2	70		
3.What is the natural diversity of **fish** species with a preference for different flow depth classes	3	60		
4. What is the natural diversity of **fish** species with various tolerances to modified water quality	4	20		
FISH ECOLOGICAL CATEGORY	10	250	**50.1**	**D**
AQUATIC INVERTEBRATES				
1. What is the natural diversity of **invertebrate** biotopes	2	80		
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements	3	100		
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality	1	20		
AQUATIC INVERTEBRATE ECOLOGICAL CATEGORY	**6**	200	**48.1**	**D**
INSTREAM ECOLOGICAL CATEGORY		450	**48.8**	**D**

INSTREAM ECOLOGICAL CATEGORY WITH CONFIDENCE	Confidence rating	Proportions	Modified weights
Confidence rating for **fish** information	4	0.44	22.27
Confidence rating for **macroinvertebrate** information	5	0.56	26.69
	9	1.00	48.96
INSTREAM ECOLOGICAL CATEGORY	**EC**		**D**

RIPARIAN VEGETATION	EC %	EC
RIPARIAN VEGETATION ECOLOGICAL CATEGORY	**41.3**	**D/E**

ECOSTATUS	Confidence rating	Proportions	Modified weights
Confidence rating for instream biological information	4.55556	0.69	34.02
Confidence rating for riparian vegetation zone information	2	0.31	12.60
	6.55556	1.00	46.62
ECOSTATUS	**EC**		**D**

Table 4.27. Level IV EcoStatus results and ecological category of Site 5 on the Ngwavuma River.

INSTREAM BIOTA	Importance Score	Weight	EC %	EC
FISH				
1.What is the natural diversity of **fish** species with different flow requirements	1	100		
2.What is the natural diversity of **fish** species with a preference for different cover types	2	70		
3.What is the natural diversity of **fish** species with a preference for different flow depth classes	3	60		
4. What is the natural diversity of **fish** species with various tolerances to modified water quality	4	20		
FISH ECOLOGICAL CATEGORY	10	250	**44.4**	**D**
AQUATIC INVERTEBRATES				
1. What is the natural diversity of **invertebrate** biotopes	2	80		
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements	3	100		
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality	1	20		
AQUATIC INVERTEBRATE ECOLOGICAL CATEGORY	**6**	200	**50.3**	**D**
INSTREAM ECOLOGICAL CATEGORY (No confidence)		450	**48.0**	**D**

INSTREAM ECOLOGICAL CATEGORY WITH CONFIDENCE	Confidence rating	Proportions	Modified weights
Confidence rating for **fish** information	4	0.44	19.73
Confidence rating for **macroinvertebrate** information	5	0.56	27.94
	9	1.00	47.68
INSTREAM ECOLOGICAL CATEGORY	**EC**		**D**

RIPARIAN VEGETATION	EC %	EC
RIPARIAN VEGETATION ECOLOGICAL CATEGORY	**58.8**	**C/D**

ECOSTATUS	Confidence rating	Proportions	Modified weights
Confidence rating for instream biological information	4.55556	0.69	33.13
Confidence rating for riparian vegetation zone information	2	0.31	17.94
	6.55556	1.00	51.07
ECOSTATUS	**EC**		**D**

Table 4.28. Level IV EcoStatus results and ecological category of Site 6 on the Usutu River.

INSTREAM BIOTA	Importance Score	Weight	EC %	EC
FISH				
1.What is the natural diversity of **fish** species with different flow requirements	1	100		
2.What is the natural diversity of **fish** species with a preference for different cover types	2	70		
3.What is the natural diversity of **fish** species with a preference for different flow depth classes	3	60		
4. What is the natural diversity of **fish** species with various tolerances to modified water quality	4	20		
FISH ECOLOGICAL CATEGORY	10	250	**66.3**	**C**
AQUATIC INVERTEBRATES				
	3	90		
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements	1	100		
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality	3	20		
AQUATIC INVERTEBRATE ECOLOGICAL CATEGORY	**7**	210	**63.7**	**C**
INSTREAM ECOLOGICAL CATEGORY (No confidence)		460	**64.8**	**C**

INSTREAM ECOLOGICAL CATEGORY WITH CONFIDENCE	Confidence rating	Proportions	Modified weights
Confidence rating for **fish** information	4	0.44	29.47
Confidence rating for **macroinvertebrate** information	5	0.56	35.39
	9	1.00	64.86
INSTREAM ECOLOGICAL CATEGORY	**EC**		**C**

RIPARIAN VEGETATION	EC %	EC
RIPARIAN VEGETATION ECOLOGICAL CATEGORY	**82.3**	**B**

ECOSTATUS	Confidence rating	Proportions	Modified weights
Confidence rating for instream biological information	4.55556	0.69	45.07
Confidence rating for riparian vegetation zone information	2	0.31	25.11
	6.55556	1.00	70.18
ECOSTATUS	**EC**		**C**

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5 POPULATION STRUCTURE, HEALTH STATUS AND REPRODUCTION STRATEGIES OF SELECTED FISH SPECIES FROM THE PHONGOLO RIVER AND FLOODPLAIN

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5.1 Introduction

One of the major economically important fish species of this region is the tigerfish, *Hydrocynus vittatus*, one of South Africa's most coveted angling fish species (Van Loggerenberg, 1983; Smit et al., 2009). However, the numbers of this species have declined greatly over the past decades not only due to their limited distribution, but as a result of pollution, weirs, and over-exploitation (Van Loggerenberg, 1983; Steyn et al., 1996; Skelton, 2001; Smit et al., 2009).

Two indigenous cichlid species, namely the Mozambique tilapia *Oreochromis mossambicus* (Peters, 1852) and the redbreast tilapia, *Coptodon* (*Tilapia*) *rendalli* (Boulenger, 1896) are highly valued and extensively utilised target species of subsistence fishers in the Phongolo floodplain region of South Africa. Of concern is that *O. mossambicus* was recently added to the Threatened or Protected Species (TOPS) list (NEMBA, 2013), evidently because of the threat posed to the genetic integrity of this species caused by hybridisation with the alien cichlid *Oreochromis niloticus* (Van der Bank & Deacon, 2007).

Although not of direct economic importance, the two species of Gobiidae found in the system, namely *Glossogobius giuris* and *Glossogobius callidus,* are widely utilised by the local community as a protein source and serve as one of the main fodder fish for predators such as the tigerfish. With regard to their Red Data Category (IUCN Red Data List), both species are considered as Least Concern (Cambray & Swartz, 2007; Larson & Britz, 2012). According to the authors there are no major known threats to this species. Potential threats include activities that may damage or modify the river system (e.g. impoundments) which may adversely affect recruitment, utilisation as a food fish, local populations affected by water abstraction, pollution or sedimentation.

Due to the above-mentioned social, economic and environmental importance of these five indigenous fish species, the aim of this section of the study was thus to assess the health status and reproduction strategies of these species in a protected part of the Phongolo floodplain, the

Ndumo Game Reserve. The Nyamithi Pan (Chapter 2, Figure 2.10) is a perennial pan located in the eastern section of the Ndumo Game Reserve and when full, the outflow decants into the Phongolo River. The pan receives water from a relatively small catchment and the outflow is controlled by a small weir (Chapter 2, Figure 2.13).

To the authors' knowledge, the role of this protected area as refugia for aquatic biodiversity has never been established, nor has the health status of the species within this area been determined. To resolve the above the objectives of this section of the study were to determine the community structures and the health status of the five selected species at sites inside and outside the protected area and to compare the results with each other.

5.1.1 Population structures and age

In order to accurately determine the population structure of fish one has to sample extensively to ensure that the sample represents the entire fish population and therefore the sampling methods must enable the researchers to collect representatives of each size class of that population. One of the most important characteristics of a population is its age structure.

Over the past decades scientists have used a variety of ageing methods, but the study of annuli deposited in the calcified structures of fish is the preferred method; these include scales, opercular covers, spines and fin rays, vertebrae and otoliths (Secor et al., 1992; Wischniowski & Bobko, 1998; Campana, 2001). Otoliths are the most common and accurate methods used for age determination of various species, since they contain the best permanent pattern of fish growth, as they are internal and are not exposed to harsh outer conditions (Wischniowski & Bobko, 1998). The application of otolith studies revolutionised our understanding of fish populations, their integrity and the management thereof. The chronological properties of otoliths are unparalleled in the animal world, allowing accurate estimates of age and growth at both the daily and the yearly level (Campana & Thorrold, 2001). Otolith interpretation and application studies are used to further understand the biology and ecology of any given species. The knowledge generated from otoliths yields valuable information on growth, mortality rates, recruitment and response to environmental factors, such as change in water temperature and food availability (Campana & Thorrold, 2001; Wischniowski & Bobko, 1998; Paxton & King, 2009). Age estimation of fish involves an assessment of the age of individuals by means of enumerating the daily, seasonal, or annual variations in growth in their calcified structures (Paxton & King, 2009). Otoliths are the preferred method for fish ageing since these are usually the first calcified structures to be laid down during the early life stages and are also believed to reflect growth more accurately than other structures (Campana & Neilson, 1985).

There are two methods for validating the age of fishes. These methods can either be direct or indirect validation (Wischniowski & Bobko, 1998). Direct validation involves rearing known-age larvae; however, this method can be difficult for species such as *H. vittatus* as was shown in a study by Van Loggerenberg (1983) where it was reported that female *H. vittatus* do not become sexually mature in captivity. Another direct validation is by chemically marking the otolith with chemical compounds (e.g. oxytetracycline hydrochloride) which are then incorporated into the calcium matrix of the bony structures and produce a mark in the otolith (Wischniowski & Bobko, 1998). This serves as a time reference that can be investigated at a later stage. This technique involves externally tagging the fish with dart-tags and recapturing them after a minimum period of one year. When these chemically tagged fish are recaptured, the otoliths are examined and the number of annuli deposited distal to the chemical mark is then compared to the time at liberty after tagging (Wischniowski & Bobko, 1998). The latter method is considered to be the traditional validation method; however, it requires a large sample size and the effectiveness is dependent on the recapture rate.

Indirect validation is based on the estimation of age by measuring the frequency of occurrence of various parameters, of which length-frequency are the most common (Wischniowski & Bobko, 1998). This method is most accurate during rapid growth of juvenile fish and becomes less accurate at maturity and/or slow growth rates. In this study no validation on the age determination was carried out due to time constraints; however, the ageing section of this study determined process errors in the form of errors in precision and accuracy due to the lack of validation (Gerber et al., 2009).

Fish have three pairs of otoliths located on each side of the head (bilateral symmetry) and posterior to the cranium (Secor et al*.,* 1992) (Figure 5.1A). The sagittae, being the largest pair, and the asterisci are located in close proximity within the pars inferior and are medial and ventral to the lapilli, the third pair (Secor et al., 1992) (Figure 5.1B). Otoliths play an important function in the balance and hearing of fish.

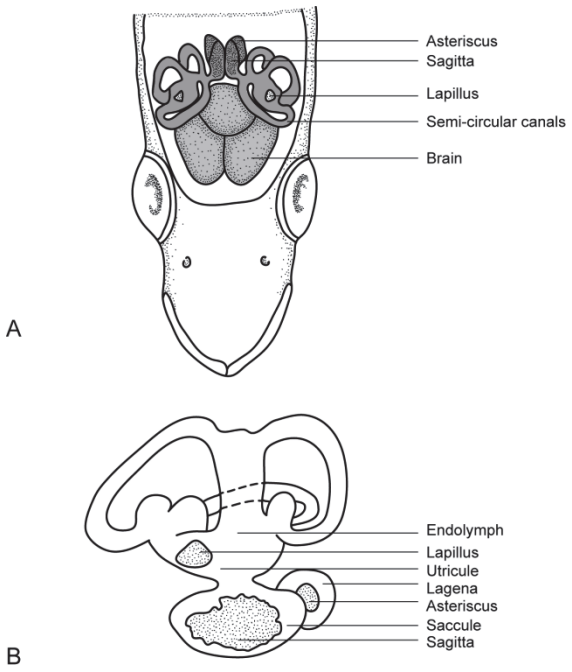


Figure 5.1. A) Dorsal view of the vestibular apparatus in a typical teleost where the top part of the head is cut away, B) anatomy of the vestibular apparatus (adapted from Secor et al., 1992).

Patterns of annulus formation in otoliths are a result of fast summer growth and slow winter growth, thus they are directly equivalent to seasonal changes (Wischniowski & Bobko, 1998; Campana & Thorrold, 2001). The annuli formed are mainly differentiated by the amount of material deposited during summer or winter. Wide translucent bands are formed during summer followed by thinner opaque bands formed during winter. The combination of one translucent band and its adjacent opaque band is referred to as an annulus and represents one year's growth (Wischniowski & Bobko, 1998).

The discovery of daily growth increments (Panella, 1971) led to the determination of hatch dates and relating these parameters to environmental variables. Daily growth increments result from the differential deposition of calcium carbonate (in the aragonite 2 configuration) and a protein (otolin) over a twenty-four hour period resulting in a sequence of contrasting opaque and hyaline bands through the otolith (Paxton & King, 2009). Campana and Nielson (1985) suggested that the formation of daily growth increments is attributable to an endocrine-driven endogenous circadian rhythm that is entrained by photoperiod. The rate of increment deposition is species-specific (Jones, 1986) and there are many variables influencing the rate of deposition such as temperature, feeding patterns and environmental factors (Brothers et al*.,* 1976; Paxton & King, 2009).

5.1.2 Fish health (macroscopic assessment)

The health of fish in this study was determined by using a macroscopic health assessment (fish health assessment index, FHAI) (Adams et al., 1993) as well as a microscopic health assessment (histology-based assessment) (Zimmerli et al*.,* 2007). The combination of these two assessments was used to strengthen the determination of the health of the selected species and their populations.

The health of organisms reflects the biotic integrity of an ecological system (Adams et al., 1993). Being at the top of the aquatic food chain, fish are generally regarded as the representative indicators of the overall system health (Adams et al., 1993). Schmitt and Dethloff (2000) discovered that contaminants bioaccumulate in aquatic organisms. This means that if an organism occupies a higher trophic level, the contaminants will increase due to biomagnification. In the Phongolo floodplain concerns have been raised about the accumulation of DDT in certain fish species including *H. vittatus* and *O. mossambicus* (Bouwman et al., 1990; McHugh et al., 2011).

Fish are subjected to a variety of stressors in their natural environment. These stressors can be either natural occurrences, such as temperature fluctuation, predation, food availability, habitat availability and other episodic variables, or anthropogenic stressors such as pollution and water extraction (Adams et al., 1993). When fish are challenged by these stressors, valuable physiological energy is diverted in order to deal with the stress, ultimately influencing growth and reproduction negatively (Barton & Schreck, 1987; Wedemeyer et al., 1990; Adams et al., 1993).

Adams et al*.* (1993) developed a quantitative FHAI which allowed the comparison of fish from different systems with one another. This index is a simple and inexpensive rapid assessment of the health of fish populations in the wild (Adams et al., 1993). Numerical values are assigned to particular alterations and the severity thereof. This index followed the necropsy approach of Goede and Barton (1990) which includes the following set of variables: (1) three blood parameters (haematocrit, leukocrit and plasma protein); (2) length, weight and condition factor; (3) fish with normal or abnormal eyes, gills, spleens, kidneys, pseudobranchs and livers (expressed in %); and (4) index values of damaged fins, skin, thymus, hindgut inflammation, fat deposits and the colour of the bile (Adams et al., 1993). When zero abnormalities or alterations were noted a score of 0 was assigned, a score of 10 was assigned to few alterations, a score of 20 was assigned when moderate alterations were noted and a score of 30 was assigned when severe alterations were noted. The data gathered on the variables mentioned above are analysed and evaluated using a summary of the means for the variables in group 4, a summary of the percentage of normal in group

3, means and variances of the blood parameters in group 1 and length-weight relationship (LWR) and condition factor data in group 2 (Adams et al., 1993).

The purpose of the fish health assessment index is to detect changes in the health of fish populations early enough to take remedial actions (Adams et al., 1993). Once a trend is indicated in the health of individuals of such a population, more detailed procedures should be applied to the problem (Adams et al., 1993). The health of fish populations sampled in the Nyamithi Pan is expressed according to the FHAI formula used by Adams et al. (1993) (Table 5.5).

5.1.3 Fish health (histological assessment)

Histological assessment of selected organs can indicate impacts of various environmental stressors such as pathogens, toxic compounds and even temperature fluctuations (Zimmerli et al., 2007). Because histology provides a rapid method to detect the effects of irritants in various tissues and organs (Bernet et al., 1999), Zimmerli et al. (2007) developed a classification system based on the work done by Bernet et al. (1999). This will allow for a semi-quantitative assessment of histological alterations in tissue structures. This classification system was based on pathological changes grouped into five different reaction patterns: (1) circulatory disturbances; (2) regressive changes; (3) progressive changes; (4) inflammation; and (5) neoplasms. The next step was to calculate an index for each of the following organs, namely kidney, liver, gills and gonads (testes and ovaries separately). The indices were scored according to the severity of the histological alterations in order to convert morphological change into a quantitative value. These indices were then used to calculate the overall fish index which can be compared to the classification table set out by Zimmerli et al. (2007).

5.1.4 *Glossogobius* breeding strategies in the Phongolo River system

During the surveys a total of 37 fish species were collected with the highest number of species collected during survey 1 followed by survey 2. Thirteen species were recorded at all the sites throughout the surveys with Cyprinidae being the most diverse family followed by Cichlidae. Even though the Cyprinidae was the most diverse family, not all species were present at all the sites and in all the surveys. It was, however, observed that two species of the family Gobiidae were present at all the sites during all the surveys. This suggested that they were well adapted to current conditions in the Phongolo River. Based on this finding, it was decided to investigate the breeding strategy of *Glossogobius* as one of the adaptations of the species.

5.2 Materials and methods

Data collected from a series of five surveys (see Table 2.14 in Chapter 2 for dates) were used for the assessment of the various indices. Otoliths were collected from *H. vittatus*, *O. mossambicus* and *C. rendalli* during all the surveys for age determination. The fish collected during the September 2013 survey were used for the macroscopic health assessment (FHAI) and the microscopic health assessment (histology-based). The fish collected during the April 2014 survey were used to determine the gonadal development stages to establish sexual maturity.

5.2.1 Ageing

Two different sets of otoliths were collected for the different species. Gerber et al. (2009) determined that the lapillus otoliths were the most accurate structure to age *H. vittatus* and Weyl and Hecht (1998) used the sagittal otoliths of *O. mossambicus* and *C. rendalli*, thus the lapillus otoliths (*H. vittatus*) and sagittal otoliths (cichlids) were removed and assessed.

Each fish was measured to the nearest 10 mm (SL), photographed and weighed and then dissected to remove the otoliths (Figure 5.2 A). Following removal, each otolith was carefully dried with tissue paper and transported to the lab. The left side otoliths of each fish were heated on a hot plate at 150°C (Figure 5.2 B) for three minutes on each side until it changed to a light brown colour (Figure 5.2 C). This enhanced the opaque bands and makes the annual growth bands more visible under the light microscope (Wischniowski & Bobko, 1998; Weyl & Hecht 1998). If the left otolith was broken or damaged, the right otolith was used. Once cooled down, the otoliths were mounted on resin bases that were prepared beforehand using moulds as described in Secor et al. (1992) (Figure 5.2D). After all the otoliths had been mounted, a second layer of resin was poured over to cover the otoliths evenly (Figure 5.2 D). The moulds were then placed in a vacuum chamber and left to dry for 24 hours. After hardening, the best sectioning plane was marked and the mounted otoliths were sectioned with the otolith saw (Figure 5.2E).

A thin section was cut through the centre of the mounted otolith using a double-blade diamond-edged otolith saw (Figure 5.2F). Cut sections were then mounted on microscope slides using DPX. This also enhanced the clarity of the otoliths when viewed under a light microscope (Gerber et al., 2009). An annulus was considered to be valid when it comprised of an opaque and translucent zone that was continuous and could be followed around the entire structure of the otolith. If not, the deposition was classified as a false annulus (Gerber et al., 2012).

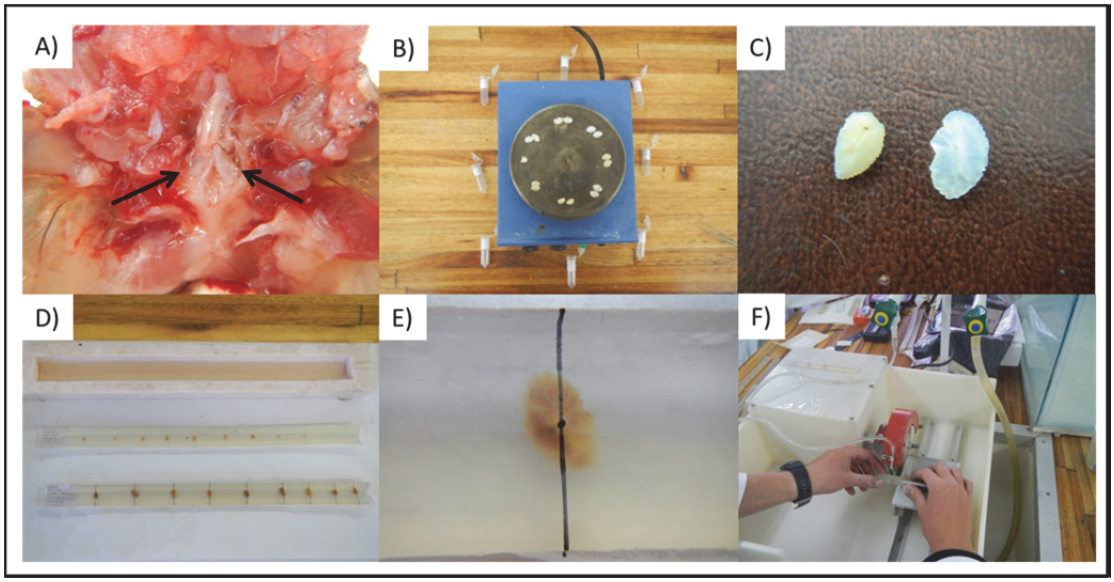


Figure 5.2. A-F): Otolith preparation and sectioning: A) removal of otoliths, B) baking otoliths, C) difference in colour of a baked otolith (left) compared to non-baked (right), D) embedding the otoliths in resin, E) marking of embedded otolith for the sawing process, F) sectioning the otolith with an otolith saw.

Data analysis

The bands on each otolith were counted twice by two individual evaluators and the first readings were recorded to be repeated one week later. Evaluators were not allowed to see each other's results in order to keep the results bias. Indices of bias and precision were calculated and the precision of all the replicate age estimates was assessed by using the absolute percentage error (APE) (Beamish and Fournier, 1981) and the coefficient of variation (CV) (Campana, 2001). No process of elimination was followed, i.e. when readings differed by more than one or two bands. By convention, a hatching date of 1 January was assigned to the fish species as described by Wischniowski and Bobko (1998).

A single relative age was assigned to each otolith and was derived from the mode of the four replicate readings. This means that the reading that was most frequent was assigned to that otolith. If the mode could not be calculated the average of the four counts was taken. Data on year rings (growth bands) derived from otolith sections were fitted to the 3-parameter von Bertalanffy growth models (VBGM) in order to generate length-at-age curves. The VBGM was fitted to males and females separately.

5.2.2 Fish health assessment index (FHAI)

Captured fish were transported to a field laboratory and each specimen was weighed with a Berkley digital lip-grip scale (nearest gram) and the standard and total length measured to the nearest centimetre. The standard length and mass data were used to calculate the condition factor (Carlander, 1969). Blood was drawn using 4 mL heparinised Vacutainers®, centrifuged at 3 000 r/min for 10 minutes, the plasma transferred to 2 mL CryoTubes® and stored in liquid nitrogen for the calculation of the total blood protein levels as part of the protocol described by Adams et al. (1993). Fish were sacrificed by severing the spinal cord and a complete fish necropsy was performed following the FHAI protocol (Adams et al., 1993).

Data analysis

The mean mass and length, as well as the condition factor (CF), hepatosomatic index (HSI), gonadosomatic index (GSI), splenosomatic index (SSI) data were all tested for significance ($p<0.05$) using a one-way ANOVA (IBM SPSS ver. 22) in conjunction with Tukey's HSD (honest significant difference) test to find means that are significantly different from each other. If the differences were not significant, Dunnett's T3 test was used.

5.2.3 Histology-based assessment

Following the macroscopic health assessment, gill, liver and kidney samples were collected and fixed in 10% neutrally buffered formalin for 48 hours. The gonad samples were fixed in Bouin's solution for 24 hours. After fixation, these samples were washed using distilled water and dehydrated in a series of increasing ethanol concentrations. The concentrations were changed every hour from 30% to 50% and finally to 70%. Tissue samples were prepared using the standard histological preparation techniques (Humason, 1962).

Histological analysis

Samples from the different species were analysed with the aid of a light microscope (Nikon Eclipse 80i). A semi-quantitative histological assessment protocol of Van Dyk et al. (2009) was used to quantify the histological alterations observed in the selected organs, adapted from Bernet et al. (1999). These histological alterations were assessed according to five reaction patterns: circulatory disturbances (CD), regressive changes (RC), progressive changes (PC), tumours (T) and inflammation (I). The results of this assessment were used to calculate the following indices: gill index, liver index, kidney index, testis index and/or ovary index. The values of these indices were

used to classify the severity of histological responses using the classification system of Van Dyk et al. (2009) which is based on the scoring system of Zimmerli et al. (2007).

- Class 1 (Index <10): Normal tissue structure with slight histological alterations
- Class 2 (Index 10-25): Normal tissue structure with moderate histological alterations
- Class 3 (Index 26-35): Pronounced alterations of organ tissue
- Class 4 (Index >35): Severe alterations of organ tissue

Gonad development

The developmental stages to determine sexual maturity of testes and ovaries for the different species were determined using the criteria set out by Schmitt and Dethloff (2000) (Table 5.1).

Data analysis

The data were tested for significance ($p<0.05$) using one-way ANOVA (IBM SPSS ver. 22) in conjunction with Tukey's HSD (honest significant difference) test to find means that are significantly different from each other. If the differences were not significant, Dunnett's T3 test was used.

5.2.4 *Glossogobius* breeding strategies

At each site the available fish habitat, also referred to as velocity-depth classes, was identified based on the work of Kleynhans (2007) and a sketch map was drawn to indicate the location of each velocity-depth class. Fish was then collected in each velocity-depth class using the habitat-related protocol prescribed by Kleynhans (2007). The collected fish were placed in 20 L plastic buckets filled with water and taken to a sampling table where species were identified using Skelton (2001) identification keys. Selected specimens of *Glossogobius callidus* and *G. giuris* were removed and placed in buckets with water while all other specimens were returned to the river. The collected specimens were preserved in 10% formalin and transported to the laboratory.

Table 5.1. Histological criteria used in gonad staging of male and female C. rendalli, O. mossambicus and H. vittatus to determine sexual maturity (adapted from Schmitt and Dethloff, 2000).

Stage	Testis characteristics	Ovary characteristics
0	**Undeveloped (immature):** Little or no spermatogenic activity in germinal epithelium; immature states of spermatogenesis (largely spermatocytes); no spermatozoa observed.	**Undeveloped:** Pre-vitellogenic oocytes observed exclusively; oocyte diameter <250 µm: cytoplasm stains basophilic with haematoxylin and eosin (H&E).
1	**Early spermatogenic**: Mostly thin germinal epithelium with scattered spermatogenic activity; spermatocytes to spermatids predominate; few spermatozoa observed.	**Early development:** >90% of oocytes pre-vitellogenic, remaining oocytes early to mid-vitellogenic; oocytes slightly larger (up to 300 µm); late perinucleolus through cortical alveolar stages.
2	**Mid-spermatogenic:** Germinal epithelia of moderate thickness; moderate proliferation and maturation of spermatozoa and equal mix of spermatocytes, spermatids and spermatozoa present	**Mid-development:** Majority of observed follicles early and mid-vitellogenic; oocytes larger 300-600 µm diameter, and containing peripheral yolk vesicles; globular and uniformly thick chorion (5-10 µm in black bass, 10-20 µm in common carp); cytoplasm basophilic, yolk globules eosinophilic.
3	**Late spermatogenic**: Thick germinal epithelium; diffuse regions of proliferation and maturation of spermatozoa; all stages of development represented, spermatozoa predominate.	**Late development:** Majority of developing follicles late vitellogenic; oocyte diameter 600-1 000 µm, eosinophilic yolk globules distributed throughout the cytoplasm; chorion thickness 10-30 µm in black bass, 40-50 µm in common carp.
4	N/A	**Late development/hydrated:** Majority of developing follicles late vitellogenic; follicles much larger (>1 000 µm).
5	N/A	**Post ovulatory:** Spent follicles, remnants of the theca externa and granulosa present.

Laboratory work and calculations

In the laboratory each specimen was measured to the nearest millimetre on a measuring board. Following measurement, each specimen was blotted dry with a paper towel to remove the excess moisture and the mass determined to the nearest milligram on an electronic balance.

Body mass to length relationship

Prior to all other calculations the body mass to body length relationship was determined by constructing a scatter plot graph and fitting a trend line.

Condition factor

In order to express the physical condition of the fish the condition factor (CF) was calculated. This was done by expressing the body mass to body length ratio using the formula given below (De Villiers, 1991):

$$CF = \frac{\text{Fish mass}}{L^b} \times 100$$

where: *b* = exponential derivative that refers to the length-mass relationship

Breeding biology

Gonadal development

The gonads of the dissected specimens were visually examined to determine the sex of each fish specimen and the gonadal maturity or gonadal development classes were visually assessed and classified using the classification proposed by De Villiers (1991). Both gonads were then removed and weighed to the nearest milligram and preserved in 4% formalin for further investigation (Schulz and Schoonbee, 1998).

Reproductive seasonality

Reproductive seasonality was determined by calculating the monthly gonadosomatic index (GSI) values (De Villiers, 1991) and the maturity coefficient (MC) values (Gaigher 1969; 1976).

The GSI was calculated using the formula:

$$GSI = \frac{\text{Gonad mass (g)}}{\text{Total fish mass (g)}} \times \frac{100}{1}$$

Oocyte size and numbers

A segment of gonadal tissue was sectioned from the widest part of one of the gonads and the mass of the tissue sample was determined in milligram (Schulz and Schoonbee, 1998). The tissue sample was then placed in a test tube containing 4% formalin and vigorously shaken to liberate the oocytes from the connective tissue (Gaigher, 1976; Tómasson et al., 1984). The excess connective tissue was physically removed with tweezers and by repeated filling and decanting with water. When all connective tissue had been removed all the liquid was decanted and 1.0 mL distilled water added to the sample using an adjustable calibrated micropipette. The sample was stirred well and a 0.2 mL sub-sample was removed with a micropipette and transferred to a counting chamber. The counting chamber consisted of a Petri dish to which a grid consisting of 1 mm x 1 mm squares was attached. The number of blocks covered by the sample were counted and recorded. Oocytes were counted with the aid of a dissecting microscope at 10x and 40x magnification using accepted cell enumeration protocols (Cambray, 1992). The oocytes were counted in a minimum of 10 blocks and the average number of oocytes per block was calculated as:

$$\frac{\text{Total number of oocytes counted}}{\text{Number of blocks counted}} = \text{Average number of oocytes per block}$$

From the average number of oocytes per block, the total number of oocytes in the subsample was calculated as:

Total number of blocks covered by the sample x average number of oocytes per block = Total number of oocytes in the 0.2 mL sample (T_s)

To calculate the total number of oocytes the following formula was used:

$$T_o = \frac{T_s}{SS} \times M$$

where:

T_o = total number of oocytes in the gonads

T_s = number of oocytes in the 0.2 mL sub-sample

M = the mass of the gonads

SS = mass of segment or sub-sample

Oocyte sizes

A second 0.2 mL sub-sample was extracted and placed on a microscope slide and covered with a cover slip. The oocyte diameters were measured, using a calibrated eyepiece micrometer, to the nearest 0.001 mm at 40x magnification on a light microscope. The diameter of 100 oocytes per

subsample was measured and recorded (Ponton & De Merona, 1998). Based on the measured oocyte diameter size, the oocytes were grouped in size classes. During the counting process the yolk development of each oocyte was visually assessed and later used to classify the oocytes as primary growth, maturing or matured oocytes. Oocytes with no visible yolk were regarded as primary growth oocytes, those with granules of yolk in the cytoplasm as maturing oocytes and those with a fully developed yolk as the mature oocytes (Murua et al., 2003).

5.3 Results

5.3.1 Ageing

Hydrocynus vittatus

The otoliths (Figure 5.3) of 136 *H. vittatus* were successfully assessed for age determination. A total of 166 *H. vittatus* were caught during five surveys from 2012 to 2014 to determine the population structure of this species in Nyamithi Pan (Figure 5.7).

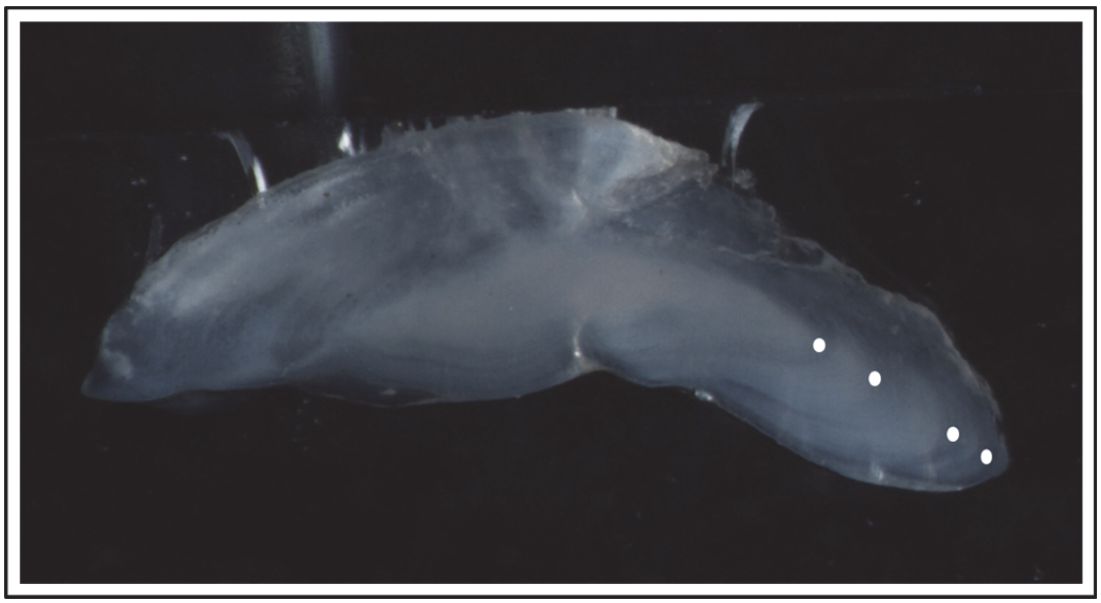


Figure 5.3. Micrograph of a sectioned lapillus otolith from a four-year-old *Hydrocynus vittatus*.

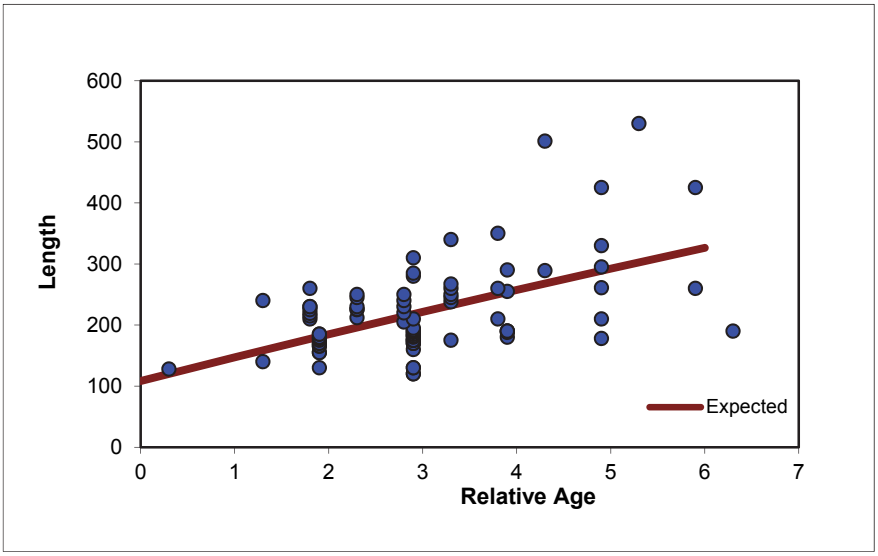


Figure 5.4. Size at relative age data of *H. vittatus*, males and females combined, obtained from sectioned otoliths (n = 136). Solid line indicates the von Bertalanffy growth models fitted to the data. Parameters are provided in Table 5.2.

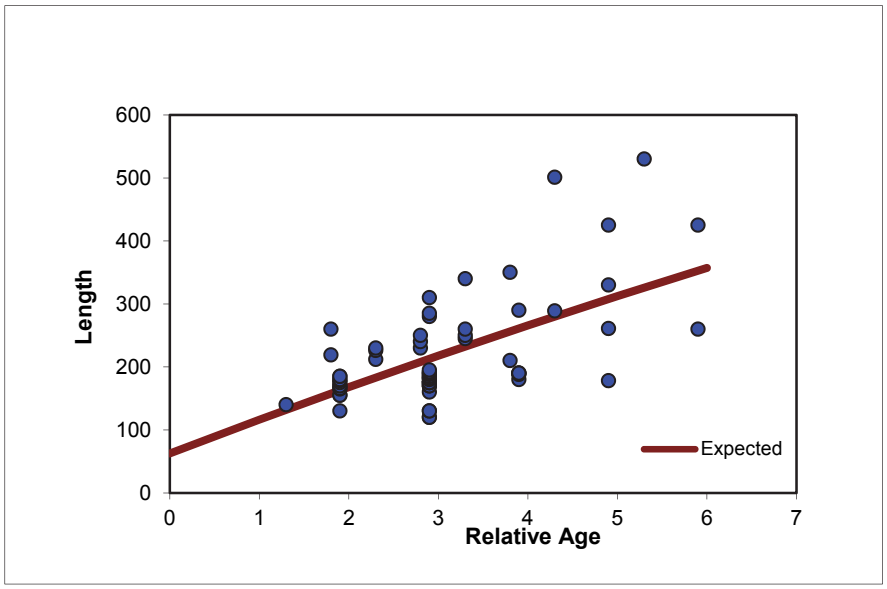


Figure 5.5. Size at relative age data of *H. vittatus* females obtained from sectioned otoliths (n = 67). Solid line indicates the von Bertalanffy growth models fitted to the data. Parameters are provided in Table 5.2.

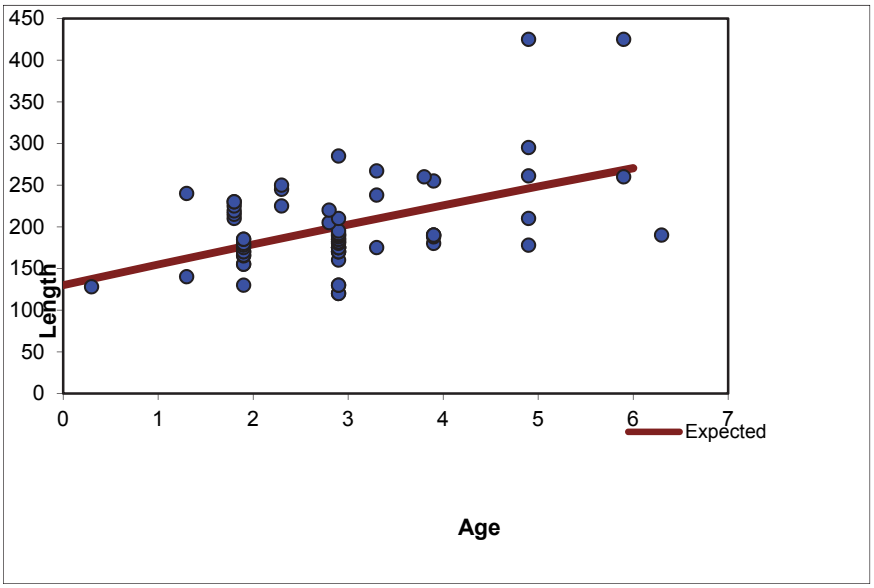


Figure 5.6. Size at relative age data of *H. vittatus* males obtained from sectioned otoliths (n = 68). Solid line indicates the von Bertalanffy growth models fitted to the data. Parameters are provided in Table 5.2

The von Bertalanffy growth model (Figures 5.4-5.6) indicates that females grow faster and become larger than males. The biggest female that was recorded during this study was 530 mm (SL) compared to the largest male of 430 mm (SL). Male and female *H. vittatus* otoliths were assigned a maximum relative age of six years.

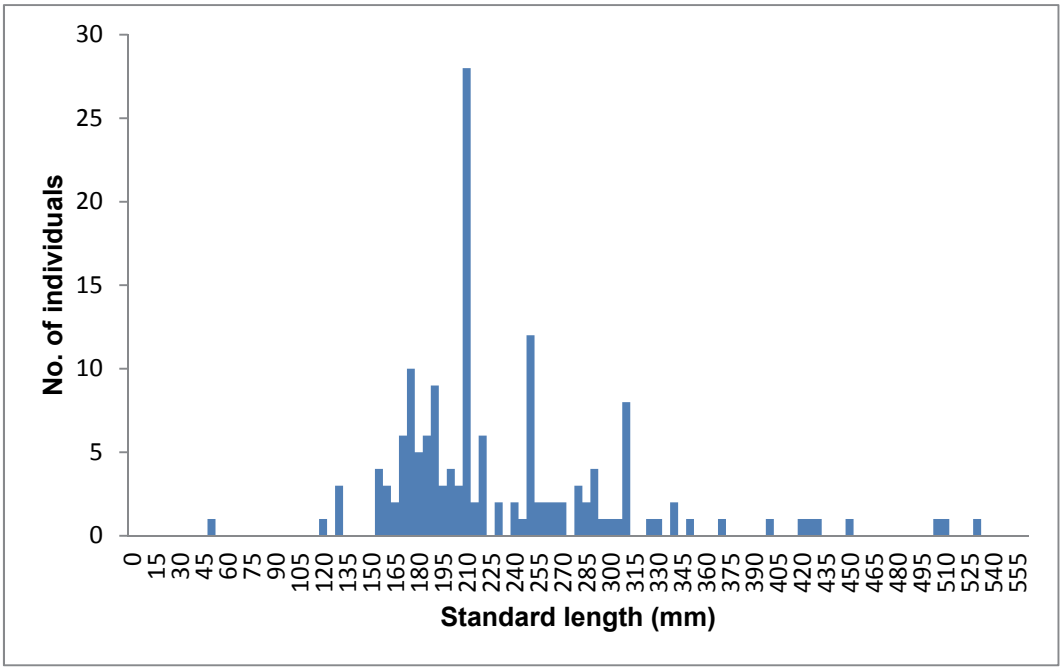


Figure 5.7. Population structure of all the *H. vittatus* caught during 2012 to 2014 (n = 166).

The majority of *H. vittatus* caught in Nyamithi Pan during 2012 to 2014 fell within the 210-255 mm length (SL) classes. These fish were estimated to be three years old. The second dominant classes are 155-170 mm fish and were estimated to be two years old.

Oreochromis mossambicus

The otoliths of 139 *O. mossambicus* (Figure 5.8) were successfully assessed for the age determination and comprised of 61 females and 78 males. A total of 383 *O. mossambicus* were caught during five surveys from 2012 to 2014 to determine the population structure of this species in Nyamithi Pan (Figure 5.12).

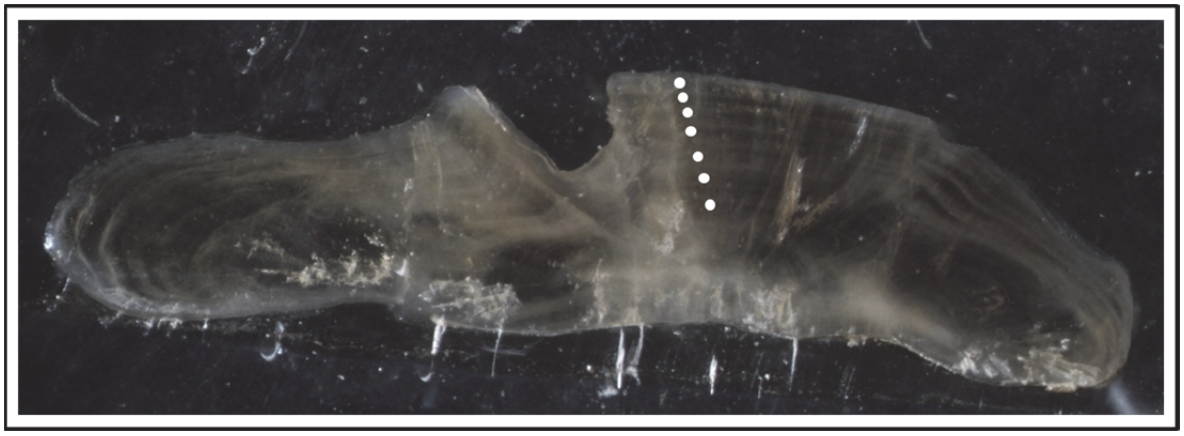


Figure 5.8. Micrograph of a sectioned sagittal otolith from a seven-year-old *O. mossambicus*.

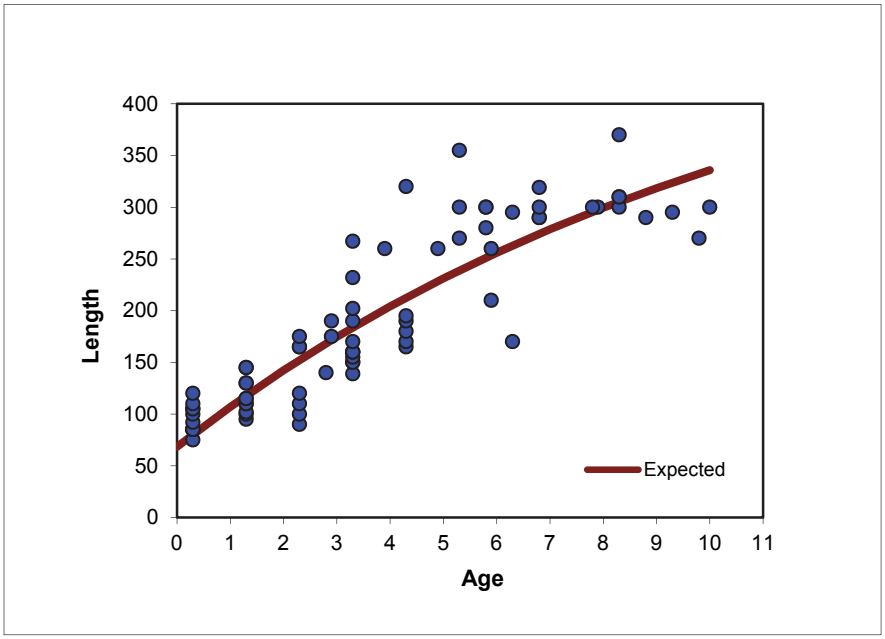


Figure 5.9. Size at relative age data of *O. mossambicus*, males and females combined, obtained from sectioned otoliths (n = 139). Solid line indicates the von Bertalanffy growth models fitted to the data. Parameters are provided in Table 5.2.

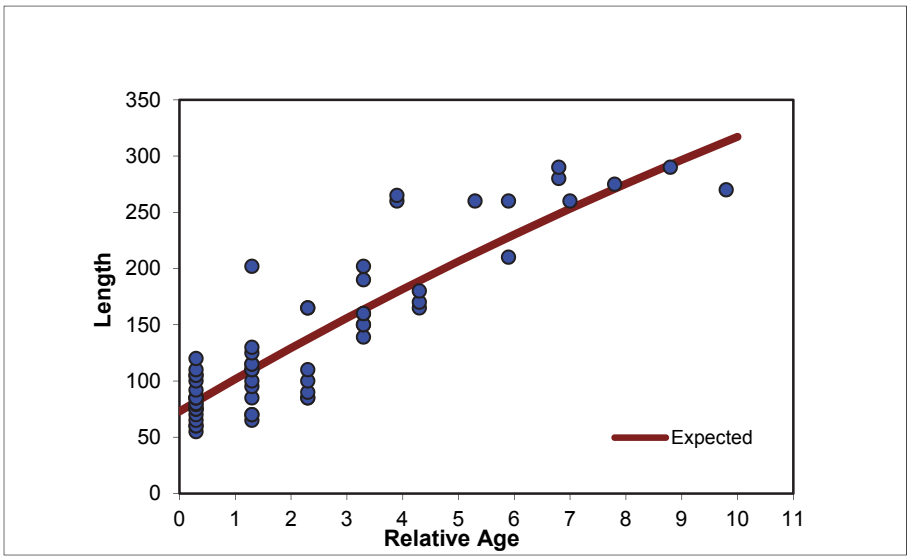


Figure 5.10. Size at relative age data of *O. mossambicus* females obtained from sectioned otoliths (n = 61). Solid line indicates the von Bertalanffy growth models fitted to the data. Parameters are provided in Table 5.2.

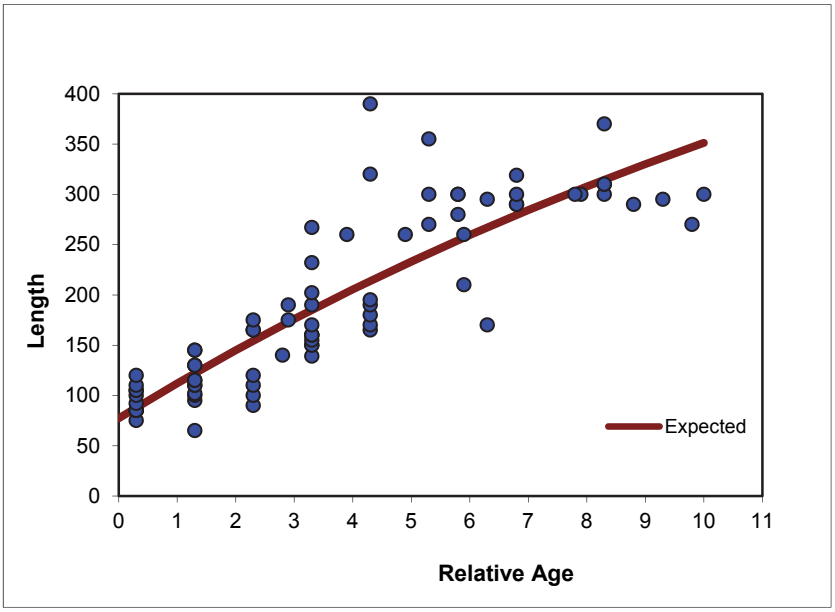


Figure 5.11. Size at relative age data of *O. mossambicus* males obtained from sectioned otoliths (n = 78). Solid line indicates the von Bertalanffy growth models fitted to the data. Parameters are provided in Table 5.2.

The von Bertalanffy growth model indicates (Figure 5.9-5.11) similar growth patterns for females and males, but males grow larger than females. The biggest female that was recorded during this study was 290 mm (SL) compared to the largest male of 390 mm (SL). Male and female *O. mossambicus* otoliths were assigned a maximum relative age of 10 years.

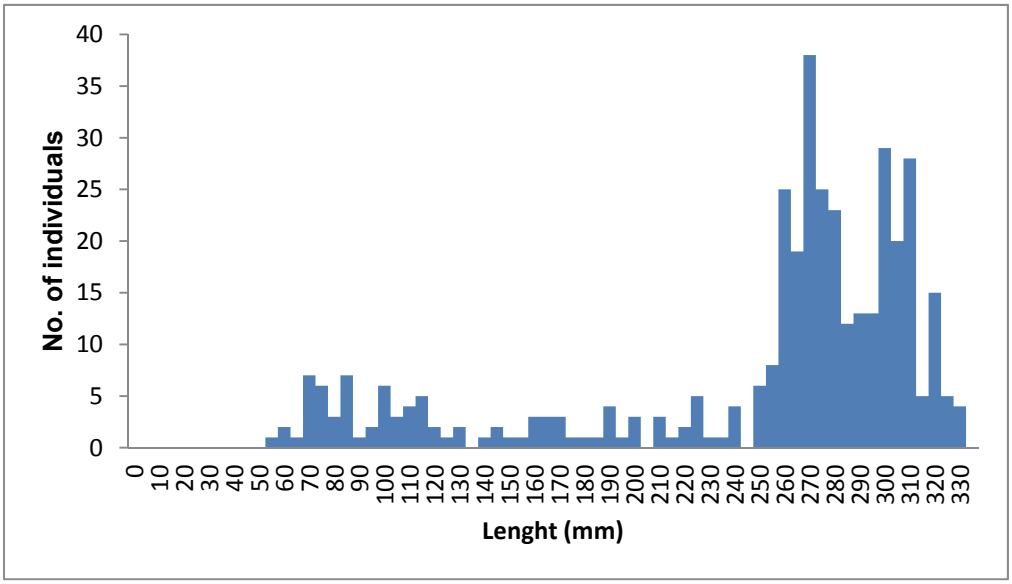


Figure 5.12. Population structure of all the *O. mossambicus* caught during 2012 to 2014 (n = 383).

The majority of *O. mossambicus* caught in Nyamithi Pan during 2012 to 2014 fell within the 260-280 mm (SL) length classes. These fish are estimated to be between four and six years old. The second dominant classes are 300-310 mm (SL) fish and are estimated to be between 8 and 10 years old. Of the 383 *O. mossambicus* caught at Nyamithi Pan 79% (n = 302) were adults.

Coptodon rendalli

The otoliths of 111 *C. rendalli* were successfully assessed for age determination. A total of 345 *C. rendalli* were caught during the five surveys from 2012 to 2014 to determine the population structure of this species in Nyamithi Pan (Figure 5.17).

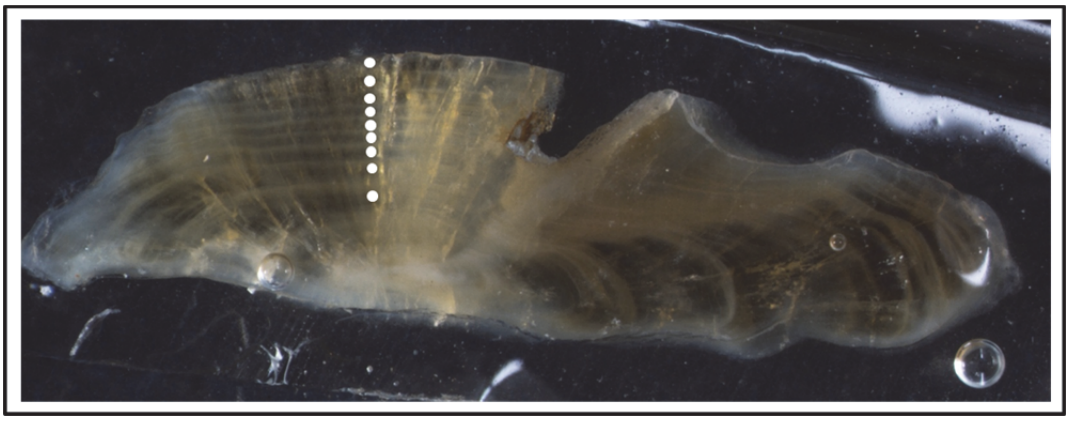


Figure 5.13. Micrograph of a sectioned sagittal otolith from a nine-year-old *C. rendalli*.

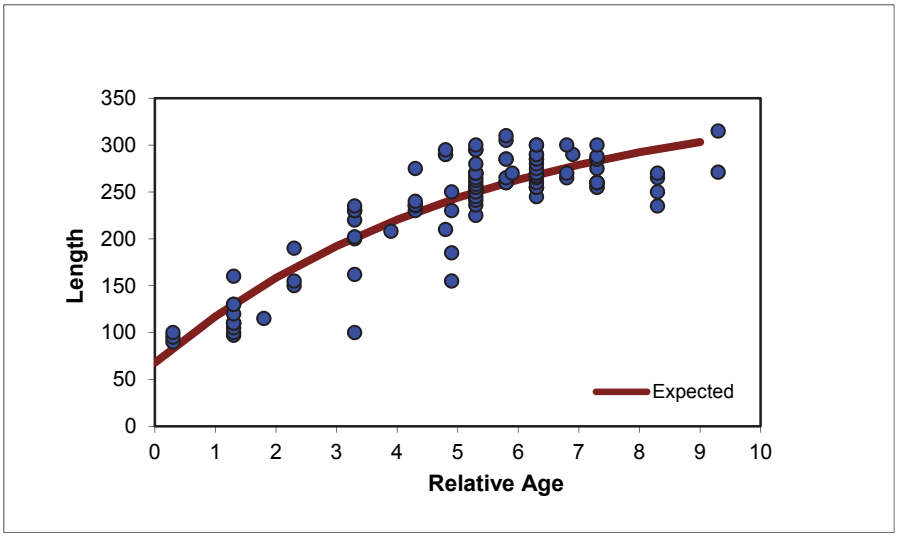


Figure 5.14. Size at relative age data of *C. rendalli*, males and females combined, obtained from sectioned otoliths (n = 111). Solid line indicates the von Bertalanffy growth models fitted to the data. Parameters are provided in Table 5.2.

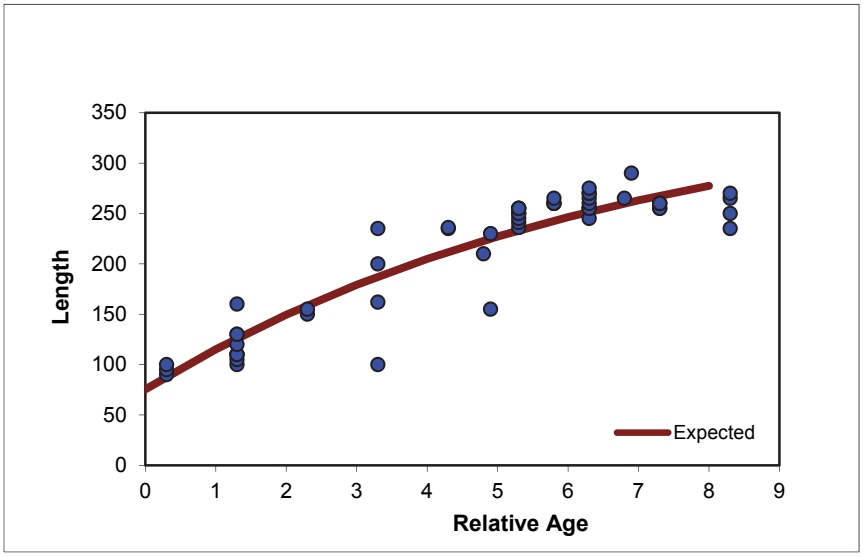


Figure 5.15. Size at relative age data of *C. rendalli* females obtained from sectioned otoliths (n = 55). Solid line indicates the von Bertalanffy growth models fitted to the data. Parameters are provided in Table 5.2.

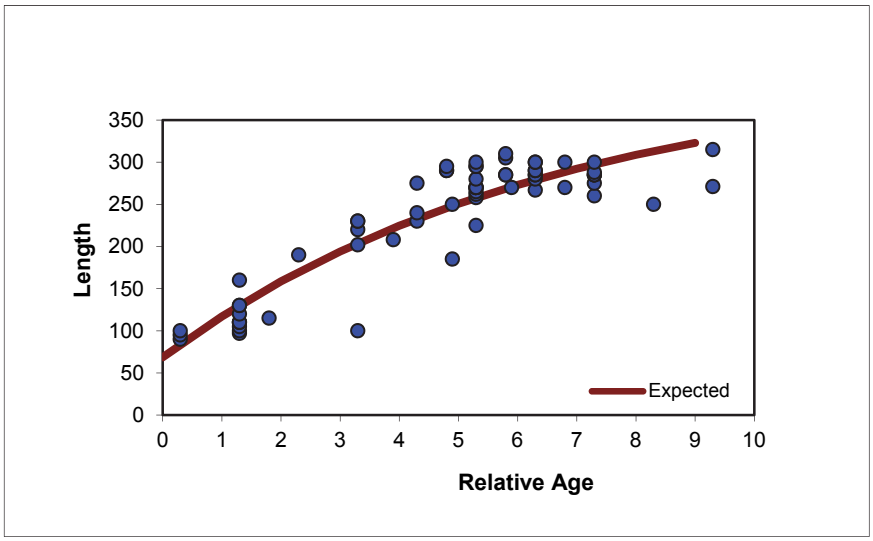


Figure 5.16. Size at relative age data of *C. rendalli* males obtained from sectioned otoliths (n = 66). Solid line indicates the von Bertalanffy growth models fitted to the data. Parameters are provided in Table 5.2.

The von Bertalanffy growth model (Figures 5.13-5.16) indicates that males grow faster and larger than females. The biggest female that was recorded during this study was 290 mm (SL) compared to the largest male of 315 mm (SL). Female *C. rendalli* otoliths were assigned a maximum of eight years compared to the male otoliths that were assigned a maximum of nine years.

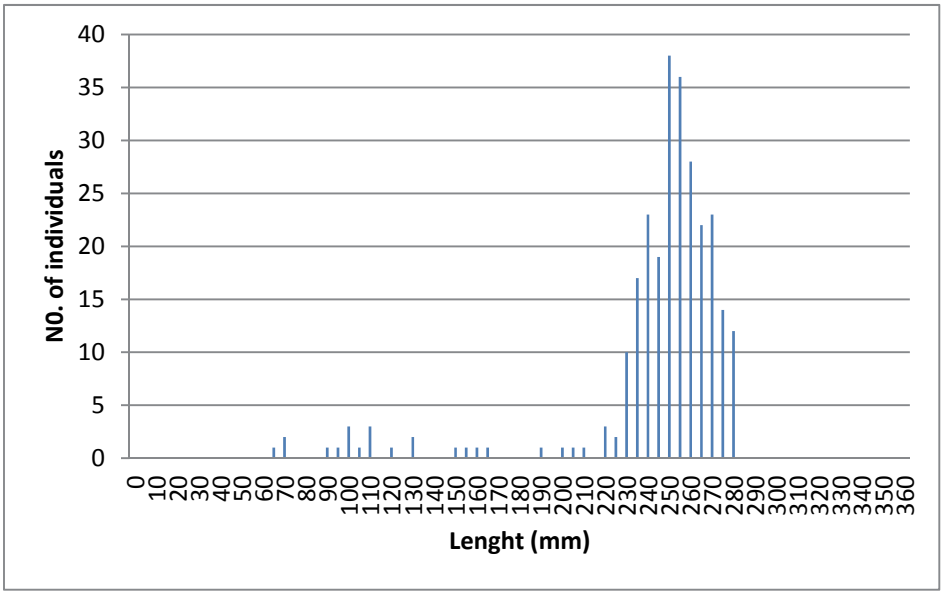


Figure 5.17. Population structure of all the *C. rendalli* caught during 2012 to 2014.

The majority of *C. rendalli* caught in Nyamithi Pan during 2012 to 2014 fell within the 250-260 mm (SL) length classes. These fish are estimated to be five years old. The second dominant classes are 265-280 mm (SL) fish and are estimated to be between six and seven years old. Of the 345 *C. rendalli* caught at Nyamithi Pan 91% were adults.

Table 5.2. Parameters for the von Bertalanffy growth curves for each species used (n = number of samples).

			L_∞		k		t_0	
Species	**n**	**sex**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**
H. vit	136	combined	1590.0	0.0002	0.027	0.004	-2.66	0.70
	67	f	1590.0	0.0008	0.036	0.005	-1.12	0.51
	68	m	1275.0	0.0005	0.022	0.004	-4.94	1.43
O. mos	139	combined	523.0	185.3	0.089	0.047	-1.58	0.34
	61	f	857.0	1360.3	0.037	0.072	-2.38	0.78
	78	m	716.7	454.5	0.056	0.047	-2.04	0.48
C. ren	111	combined	356.0	30.1	0.189	0.037	-1.12	0.20
	55	f	370.1	62.7	0.145	0.050	-1.58	0.37
	66	m	407.5	60.5	0.154	0.045	-1.20	0.25

Figure 5.18 shows the deviation between the different readings of the otoliths for each species. Of the 139 *O. mossambicus* otoliths assessed, 51 individuals did not deviate from one another, 40 deviated by one growth zone, 7 deviated by 2 growth zones, one by three growth zones and one by four growth zones. Of the 111 *C. rendalli* otoliths assessed, 41 did not deviate from one another, 57 deviated by one growth zone and 8 deviated by two growth zones. Of the 136 *H. vittatus* otoliths assessed, 31 did not deviate from one another, while 52 deviated.

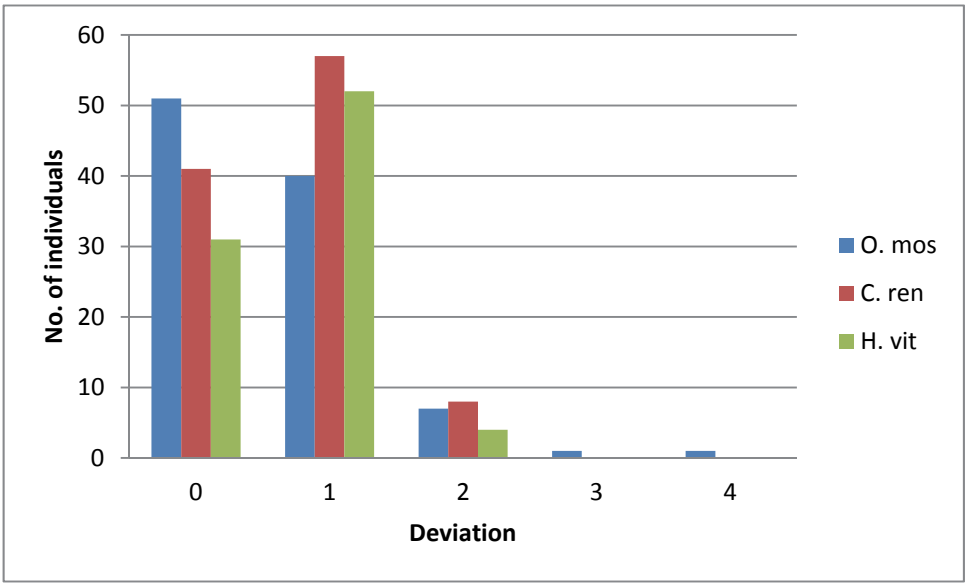


Figure 5.18. The deviation in age during the four counts for the different species used.

Precision of the replicate age estimation for the different species showed very little difference. The APE for *H. vittatus* was 10% and the coefficient of variance 13% (Table 5.3). The APE for *C. rendalli* was 8% and the coefficient of variance 10.1% (Table 5.3). The APE for *O. mossambicus* was 10.6% and the coefficient of variance 13.4% (Table 5.3).

Table 5.3. Absolute percentage error (APE) and coefficients of variation (CV) of recorded age for different species (n = number of samples).

Species	n	APE	CV
H. vit	136	10.01%	13.06%
C. ren	111	7.99%	10.11%
O. mos	139	10.60%	13.39%

5.3.2 Fish health assessment index (FHAI)

During the April 2013 survey (high flow) data were collected in order to determine the general indices such as the condition factor (CF), as well as hepatosomatic splenosomatic and gonadosomatic indices. On return during the September 2013 survey (low flow) an in-depth health assessment according to Adams et al. (1993) was carried out (Table 5.4).

April 2013

The *Hydrocynus vittatus* collected during the April 2013 survey had a condition factor (K = 3.69 ± 0.39) similar to that of the tigerfish from Zimbabwe (K = 3.06) (Dalu et al., 2013). The HSI (0.64 ± 0.17) for *H. vittatus* was within the same range as the fish caught in the Pongolapoort Dam by

McHugh et al. (2011). The GSI and SSI values were 0.30 ± 0.22 and 0.03 ± 0.02, respectively. *Oreochromis mossambicus* collected from Nyamithi Pan had a low CF (K= 3.74 ± 0.40) when compared to *C. rendalli* (K= 4.45 ± 0.59) from Nyamithi Pan. The HSI of both species collected from Nyamithi Pan where lower than the normal range (1.84 ± 0.46) for these species (Van Dyk et al., 2007). The gonadosomatic index for *O. mossambicus* was relatively low compared to the normal range (GSI = 0.40 ± 0.49) for these species (Pieterse, 2004). The splenosomatic index for most of the species caught during the April survey was higher than the normal range (SSI= 0.02 ± 0.01) (Van Dyk, 2006).

September 2013

The *O. mossambicus* collected from Nyamithi Pan were significantly ($p<0.05$) larger than those collected during April 2013. However, the CF of September 2013 was significantly lower (1.94 ± 0.19) ($p<0.05$) than that of the April 2013 survey. The *C. rendalli* collected from Nyamithi Pan were slightly bigger than those in the previous survey of April 2013 but the CF was also lower (3.85 ± 0.25) than that of the previous survey. The hepatosomatic index of the *O. mossambicus* from Nyamithi Pan was slightly higher than the normal range (0.39 ± 0.11) but showed no significant difference ($p>0.05$) compared to the previous survey. The *C. rendalli* from Nyamithi Pan on the other hand showed a significant difference ($p<0.05$) in HSI compared to that of the April 2013 survey. *Oreochromis mossambicus* showed an increase in GSI but it was still within the normal range (GSI = 0.40 ± 0.49g) for these species (Pieterse, 2004). *Coptodon rendalli* showed a significant ($p<0.05$) increase in GSI values compared to those of April 2013. Health assessment index scores were calculated for both species cichlid from Nyamithi Pan had an average score of (HAI score; 111 ± 10). *Oreochromis mossambicus* from NP were heavily infected with both external and internal parasites. The external parasite, *Lernaea cyprinacea,* had a prevalence of 100% and parasitemia ranged from 1-109 where the internal parasite, nematode (*Contracaecum* sp.), had a prevalence of 52.4% and parasitemia ranged from 1-13. *Coptodon rendalli* (HAI score; 39.5 ± 10) caught in NP were in a better condition than *O. mossambicus* caught in Nyamithi Pan and very few parasites were found on this species. The *H. vittatus* caught during the September 2013 survey (low flow) were significantly smaller ($p<0.05$) than those found during the April 2013 survey (high flow). The condition factor of *H. vittatus* dropped from K = 3.69 ± 0.39 in April 2013 to K = 1.45 ± 0.23 in September 2013. The HAI score of *H. vittatus* was (42.4 ± 16.8) with a range of between 10 and 80. *Hydrocynus vittatus* were infected with the internal nematode (*Contracaecum* sp.) in the liver and it had a prevalence of 76%, ranging from a few parasites to being severely infected.

Table 5.4. Mean body mass (g), standard length (mm), condition factor (CF), hepatosomatic index (HSI), gonadosomatic index (GSI), splenosomatic index (SSI) and health assessment index (HAI) values for *Oreochromis mossambicus, Coptodon rendalli* and *Hydrocynus vittatus* from Nyamithi Pan during two surveys. Ranges are shown in parentheses.

Survey	Species	n	Mass	Length	CF	HSI	GSI	SSI	HAI
Apr-2013	*O. mos*	15	468 ± 277 (60 - 880)	221 ± 50 (115 - 292)	3.74 ± 0.4	0.87 ± 0.14	0.10 ± 0.05	0.13 ± 0.03	-
	C. ren	13	744 ± 234 (36 - 960)	249 ± 0.6 (97 - 288)	4.45 ± 0.59	0.97 ± 0.22	0.15 ± 0.07	0.09 ± 0.03	-
	H.vit	11	688 ± 969 (35 - 2860)	289 ± 118 (128 - 530)	3.69 ± 0.39	0.67 ± 0.17	0.30 ± 0.22	0.03 ± 0.02	-
Sep-2013	*O. mos*	21	837 ± 264 (78 -1080)	278 ± 43 (140 - 319)	1.94 ± 0.19	0.86 ± 0.14	0.79 ± 1.02	0.16 ± 0.05	110.5 ± 10.2 (90 - 130)
	C. ren	20	801 ± 257 (53 - 1100)	269 ± 42 (115 - 310)	3.85 ± 0.25	1.45 ± 0.31	1.13 ± 1.20	0.13 ± 0.03	39.5 ± 10.0 (20 - 60)
	H.vit	19	195 ± 128 (58 - 680)	231 ± 35 (165 - 350)	1.45 ± 0.23	0.41 ± 0.07	0.15 ± 0.12	0.10 ± 0.15	42.4 ± 16.8 (10 - 80)

5.3.3 Histology-based assessment

The microscopic health assessment (histology-based) was done on 20 individuals of each species (*H. vittatus, O. mossambicus* and *C. rendalli*). Because *H. vittatus* is a predator, it could not be compared directly or statistically to the cichlid species and therefore the results presented in this chapter will be compared to previous studies done on this species in the same system.

Hydrocynus vittatus

The average gill index (Figure 5.19) was 1.5 and 100% of the fish fell within Class 1. The liver index was 1.4 on average and 100% of the individuals fell within Class 1. The kidney index was 2.9 and 100% of the individuals fell in Class 1. The average fish index was 5.7 and the maximum score was 11. Thus 95% of *H. vittatus* were scored in Class 1 and 5% in Class 2. These indices are summarized in Table 5.5. There was no significant difference between the testis and ovary indices for this species ($p<0.05$). Gill monogeneans were present in the secondary lamellae (Figure 5.19B).

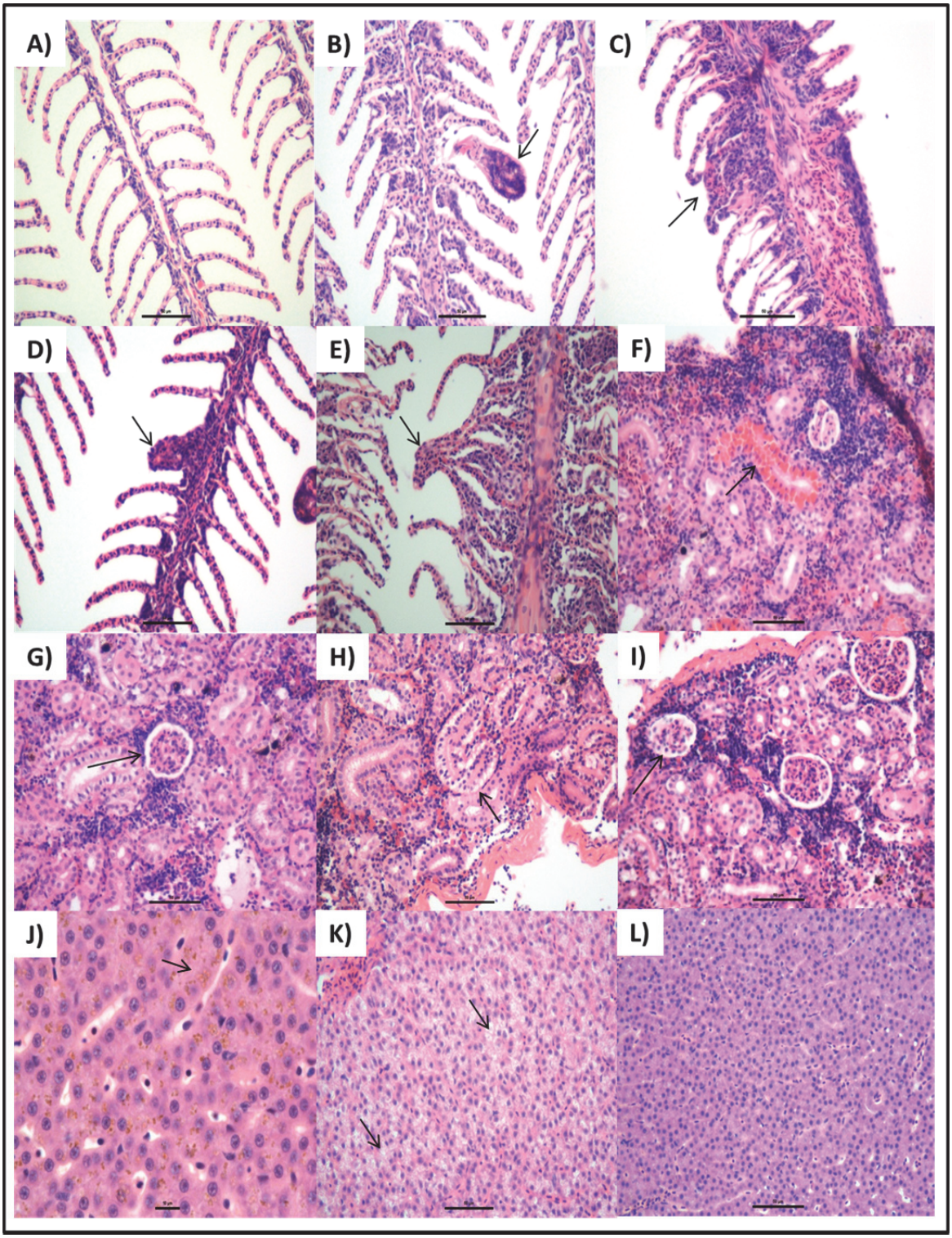


Figure 5.19. Micrographs of *Hydrocynus vittatus* gills, kidney and liver sections (5 µm) stained with H&E: A) Normal gill, B) gill monogeneans between secondary lamellae (arrow), C-D) hyperplasia of the gill epithelium (arrows), E) congestion of the gill epithelium (arrows), F) hyaline droplet degeneration in kidney tissue (arrow), G) increase in Bowman's space in kidney tissue (arrow), H) vacuolation of renal tubules in kidney tissue (arrow), J) intercellular deposits in liver tissue (arrow), K) vacuolation of hepatocytes in liver tissue (arrows), L) normal liver.

Oreochromis mossambicus

The average gill index (Figure 5.20) was 9.9 and 60% of the fish fell in Class 1, 35% in Class 2 and 5% in Class 3. The liver index (Figure 5.21) was 6.4 on average where 90% of the individuals fell within Class 1 and 10% in Class 2. The kidney index (Figure 5.20) was 2.7 and 100% of the individuals fell in Class 1. The average fish index was 19.3 and the maximum score was 34. Thus 5% of the individuals were scored in Class 1, 80% in Class 2 and 15% in Class 3. These indices are summarized in Table 5.5. There was no significant difference between the testis and ovary indices for this species ($p<0.05$).

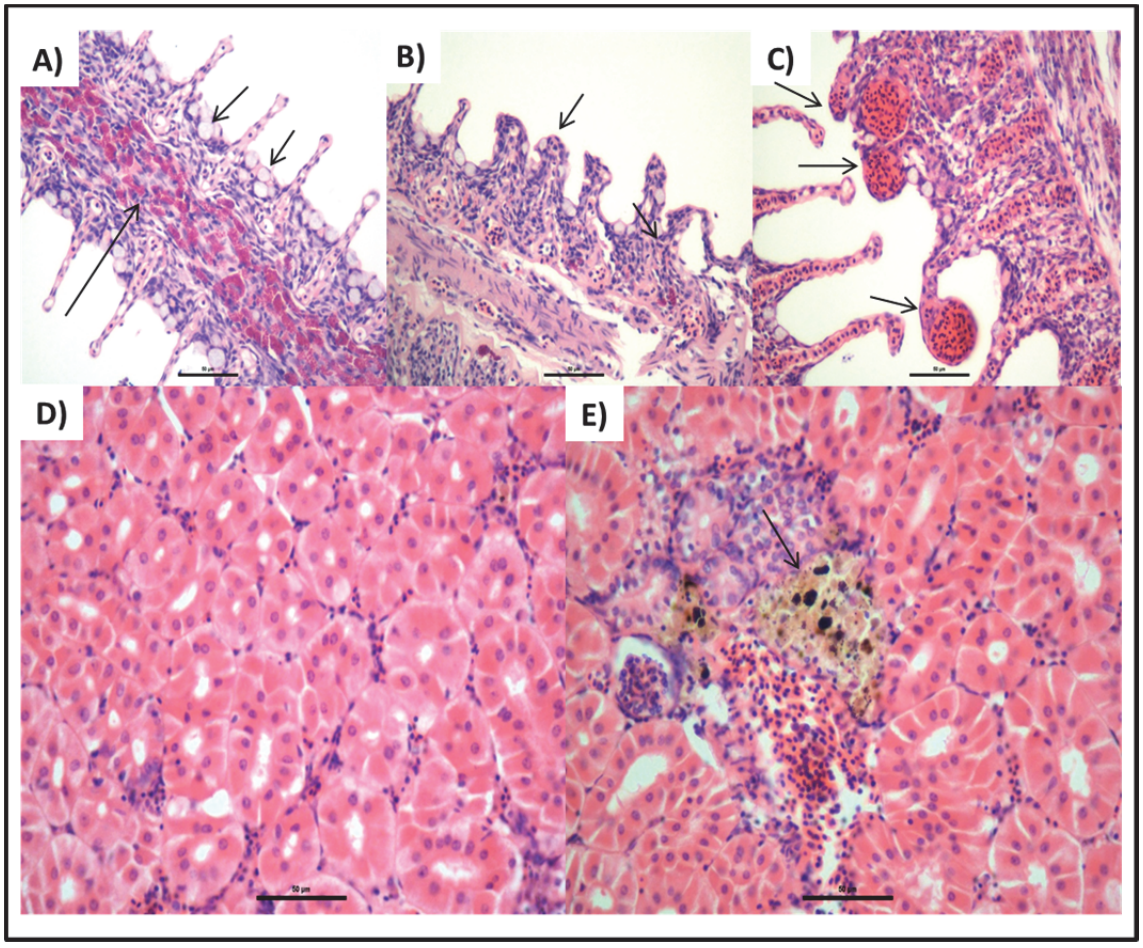


Figure 5.20. Micrographs of *Oreochromis mossambicus* gills and kidney sections (5 µm) stained with H&E: A) increase in mucus cells and infiltration of granulocytes (arrows), B) hyperplasia of the gill epithelium (arrows), C) telangiectasia and rupture of pillar cells (arrows), D) normal kidney tissue, E) increase in melano-macrophage centre in the kidney tissue (arrow).

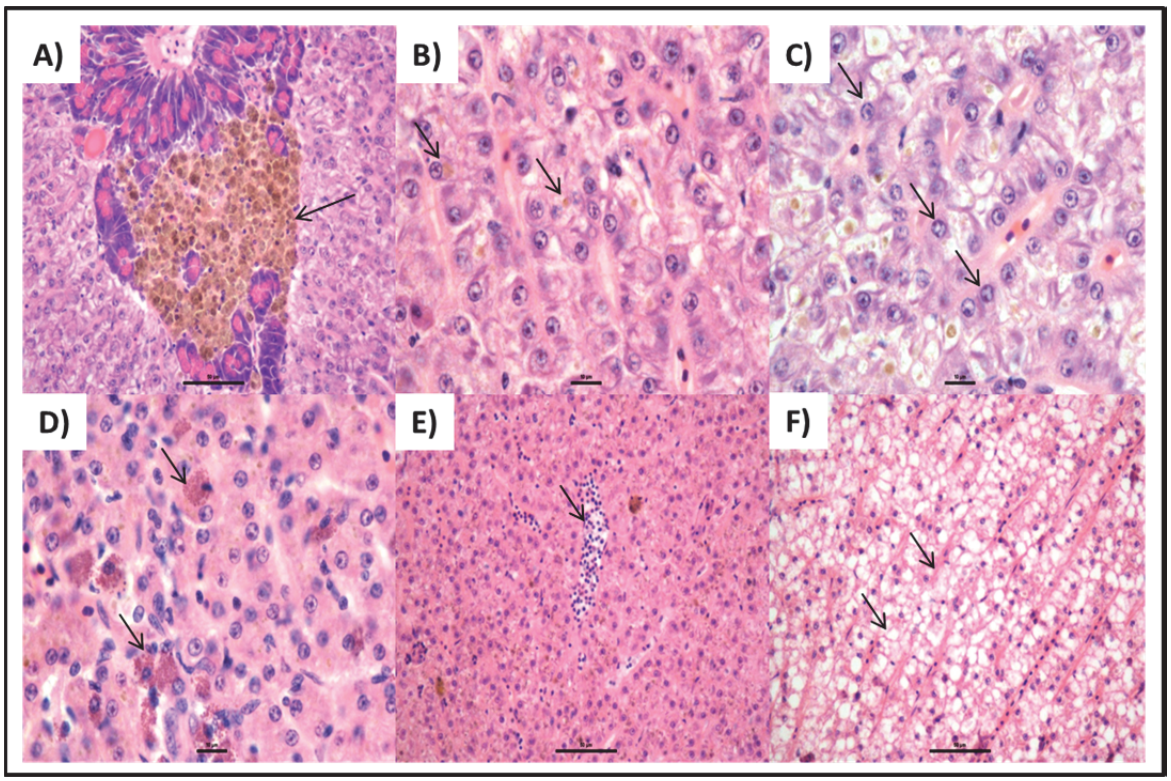


Figure 5.21. Micrographs of *Oreochromis mossambicus* liver sections (5 µm) stained with H&E: A) increase in melano-macrophage centre in the liver tissue (arrow), B) intercellular deposits in liver tissue (arrows), C) picnosis of nuclei in liver tissue (arrows), D) infiltration of granulocytes in liver tissue (arrows), E) infiltration of lymphocytes in liver tissue (arrow), F) vacuolation of hepatocytes (arrows).

Coptodon rendalli

The average gill index was 5.1 and 95% of the fish fell in Class 1 and 5% in Class 2. The liver index was 4.5 on average and 100 % of the individuals fell within Class 1. The kidney index (Figure 5.22) was 1.4 and 100% of the individuals fell in Class 1. The average fish index was 11.8 and the maximum score was 18. Thus 20% of the individuals were scored in Class 1 and 80% in Class 2. These indices are summarized in Table 5.5. There was no significant difference between the testis and ovary indices for this species ($p<0.05$).

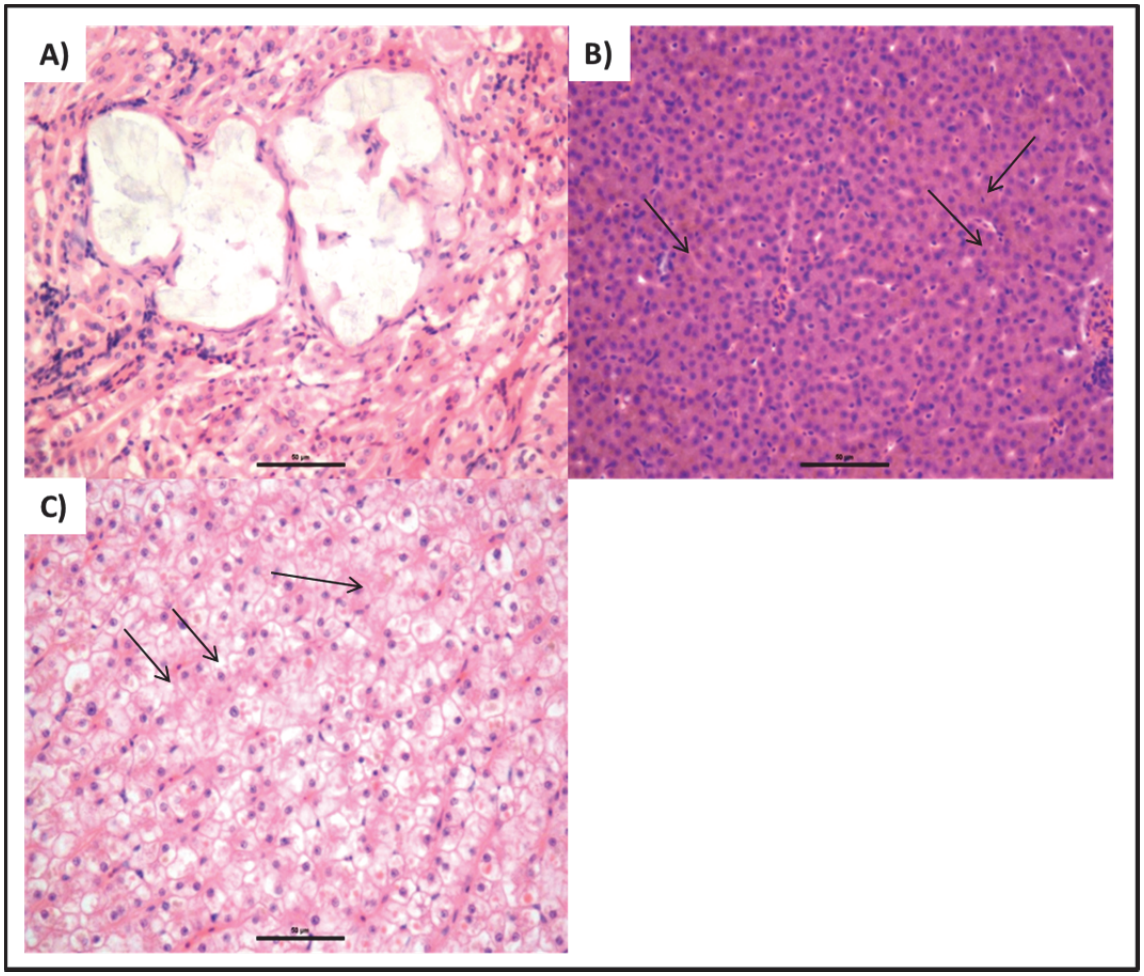


Figure 5.22. Micrographs of *Coptodon rendalli* kidney and liver sections (5 µm) stained with haematoxylin and eosin (H&E): A) nephrocalcinosis in kidney tissue, B) intercellular deposits in liver tissue (arrows), C) vacuolation of hepatocytes in liver tissue (scale: 50 µm).

Table 5.5. Mean index values for *C. rendalli*, *O. mossambicus* and *H. vittatus*. Gill index (GI), liver index (LI), kidney index (KI), testis index (TI), ovary index (OI) and fish index (FI) (ranges are shown in parentheses).

Species	GI	LI	KI	TI	OI	FI
C. rendalli	5.1 (2-11)	4.5 (0-9)	1.4 (0-5)	0	2.1 (0-3)	11.75 ±3.70 (4-18)
O. mossambicus	9.9 (4-25)	6.4 (0-12)	2.7 (0-6)	0.2 (0-3)	0.6 (0-3)	19.25 ± 6.80 (6-34)
H. vittatus	1.5 (0-5)	1.4 (0-4)	2.9 (0-6)	0	0	5.70 ± 3.50 (0-11)

5.3.4 Gonad development

Testis development

Of the 25 *H. vittatus* sampled for gonad staging analysis, 56% were males and 46% females. For the males (standard length range: 175-260 mm) 92% fell within Stage 0 of development and 8% fell within the Stage 1 of development. This stage is characterised by thin germinal epithelium with scattered spermatogenic activity; primary spermatocytes predominate followed by spermatids; few spermatozoa were observed. Due to a lack of sample size of different size classes, age-length maturity curves could not be determined for *H. vittatus* males.

Of the 41 *O. mossambicus* sampled for gonad staging analysis, 78% were males and 22% were females. For the males (standard length range: 100-310 mm) 50% fell within Stage 0 of development and 50% fell within Stage 1 or higher. Stage 0 is characterised by little or no spermatogenic activity in germinal epithelium; immature states of spermatogenesis (largely spermatocytes); no spermatozoa were observed. Stage 1 is characterised by thin germinal epithelium with scattered spermatogenic activity; spermatocytes to spermatids predominate; few spermatozoa observed. This means that 50% of the *O. mossambicus* males caught were sexually mature. Length-maturity logistic ogives for male *O. mossambicus* can be seen in Figure 5.23.

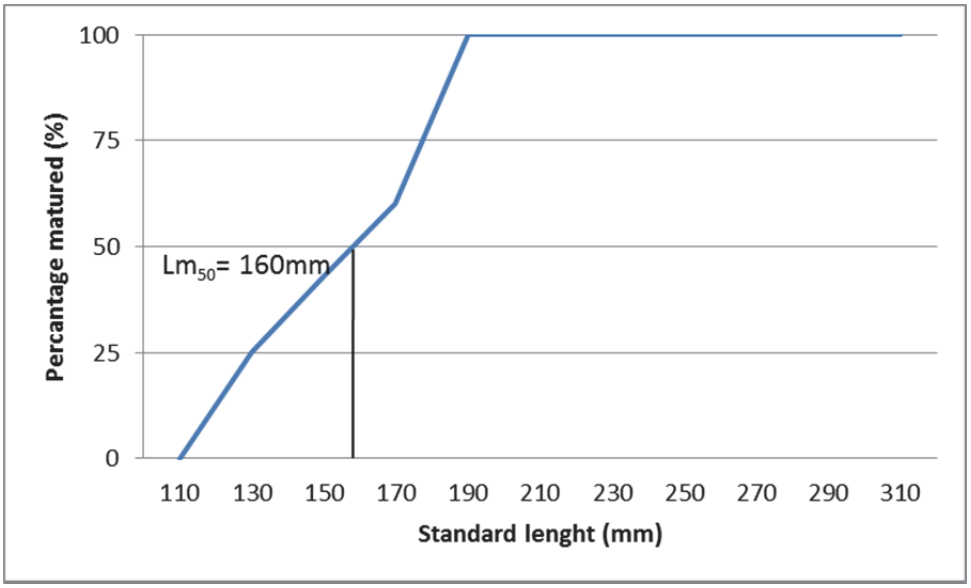


Figure 5.23. Logistic ogives depicting the length at which 50% maturity is reached for *O. mossambicus* males.

Sexual maturity for male *O. mossambicus* is reached at the relative size of 170 mm (SL) (Figure 5.23) and females at the relative size of 250 mm (SL) (Figure 5.24). The results indicate that male *O. mossambicus* reach sexual maturity earlier than the females.

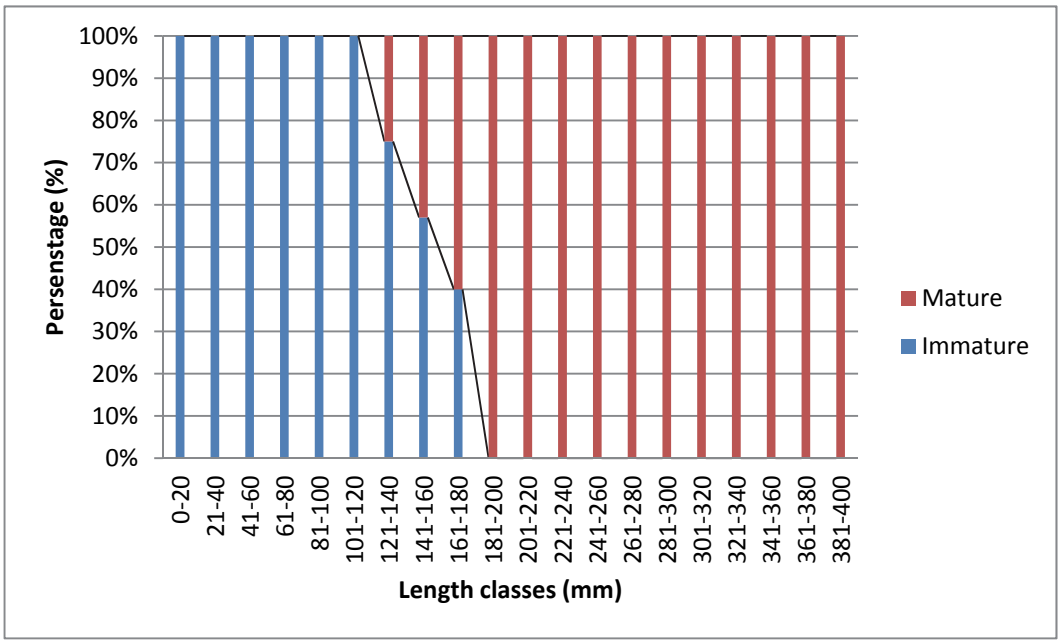


Figure 5.24. Bar graph showing relationship in percentage of immature and mature male *O. mossambicus* in each length class.

Of the 71 *C. rendalli* sampled for gonad staging 52% were males and 48% were females. For the males (standard length range: 190-315 mm) 100% fell within Stage 1 and higher. This indicates that all the males (Figure 5.25) sampled were sexually mature. Due to a lack of sample size of different size classes, age-length maturity curves could not be determined for *C. rendalli* males.

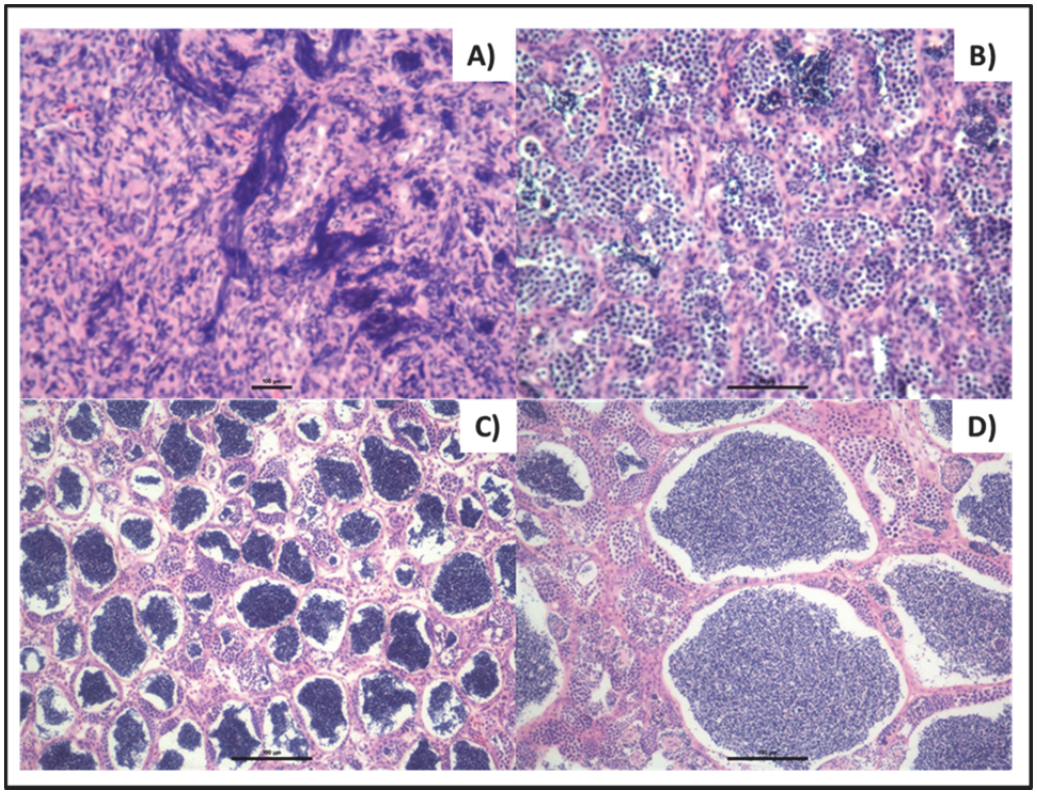


Figure 5.25. Micrographs of testis sections (5 µm) stained with H&E: A) Stage 0, B) Stage 1, C) Stage 2, D) Stage 3.

Ovary development

For the total of 11 *H. vittatus* females (standard length range: 210-350 mm), 100% fell within Stage 0 of development. This stage is characterised by pre-vitellogenic oocytes observed exclusively; oocyte diameter <250 µm: cytoplasm stains basophilic with haematoxylin and eosin (H&E). Due to a lack of sample size of different size classes age-length maturity curves could not be determined for *H. vittatus* females.

For the total of 14 *O. mossambicus* females (standard length range: 110-205 mm), 92% fell within Stage 0 of development and 8% in Stage 1 of development. Stage 1 is characterised by >90% of oocytes pre-vitellogenic, remaining oocytes early to mid-vitellogenic; oocytes slightly larger (up to 300 µm); late perinucleolar through cortical alveolar stages. Thus not all the female *O. mossambicus* caught were sexually mature yet and no age-length maturity curves could be determined for this species due to a lack of sample size of different size classes. For the total of 34 *C. rendalli* females (standard length range: 150-350 mm), 8% fell within Stage 0, 35% fell within Stage 1-3 of development and 47% fell within the Stage 5 development (Figure 5.26). Characteristics of these stages can be seen in Table 5.4. Due to a lack of sample size of different

size classes age-length maturity curves could not be determined for *C. rendalli* females because the majority were found to be adults.

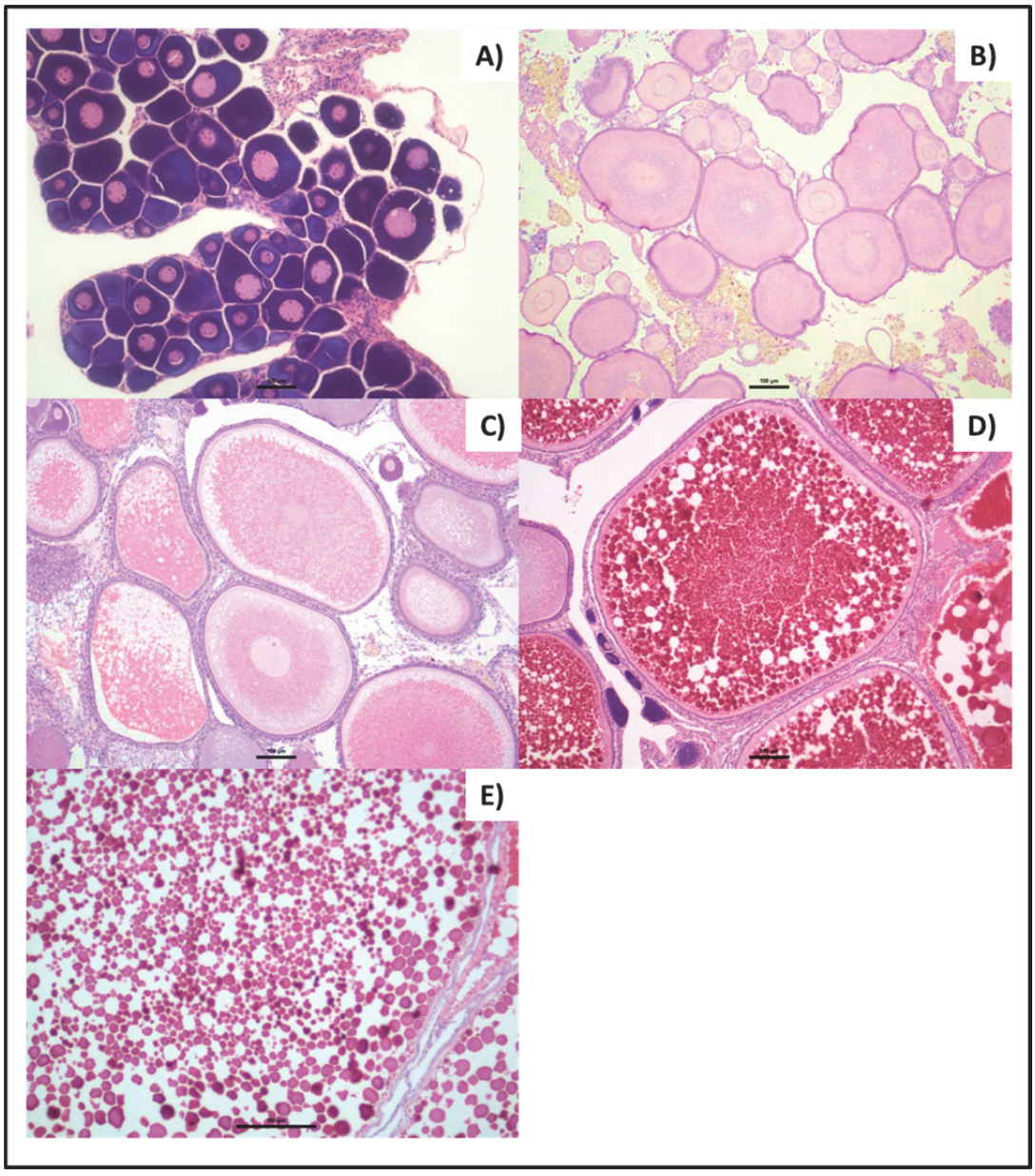


Figure 5.26. Micrographs of ovary sections (5 µm) stained with H&E: A) Stage 0, B) Stage 1, C) Stage 2, D) Stage 3, E) Stage 4.

5.3.5 *Glossogobius* breeding strategies

A total of 137 *Glossogobius* specimens were collected at the sites during the surveys and this number was dominated by *Glossogobius callidus* with 106 specimens as compared to the 31 specimens of *G. giuris* (Table 5.6). Most of the *G. callidus* specimens were collected at Site 1 followed by Site 6, while Site 3 had the lowest number. Only at Site 2 were there more *G. giuris* than

G. callidus. In all surveys the highest number of specimens was collected during survey 2. During survey 3, no specimens of *G. giuris* were collected and the lowest number of specimens was collected during survey 4 (Table 5.7).

Due to the fact that more *G. callidus* specimens were collected and because they were present at all sites and in all seasons, the decision was taken that the investigation would focus on the breeding strategy *G. callidus*.

Table 5.6. The total number of *Glossogobius callidus* and *Glossogobius giuris* specimens collected at the sites in the Phongolo River system from April to November 2013.

Site number	River	Total number of specimens	*Glossogobius callidus*	*Glossogobius giuris*
1	Phongolo	46	40	6
2	Phongolo	29	13	16
3	Phongolo	3	3	0
4	Ngwavuma	13	13	0
6	Usutu	28	27	1
9	Phongolo	18	10	8
Total		**137**	**106**	**31**

Table 5.7. The total number of *Glossogobius callidus* and *Glossogobius giuris* specimens collected during the surveys in the Phongolo River system from April to November 2013.

Survey number	Date	No. of specimens	*Glossogobius callidus*	*Glossogobius giuris*
1	April	40	27	13
2	July	48	42	6
3	September	27	27	0
4	November	22	10	12
	Total	**137**	**106**	**31**

Length-mass relationship

The length-mass relationship of *G. callidus* displayed an exponential relationship ($y = ax^b$) with a coefficient of *ca* 2.9 (Figure 5.27). In Figure 5.27 it is observed that: a) in smaller fish, up to a total length of *ca* 40 mm, the plotted points were directly on the fitted trend line; b) in the next group, with total length of up to *ca* 80 mm, the plotted points were more scattered; and c) with even more scattering in the 80 to 100 mm total length class and in fish longer than 100 mm the plotted points were widely scattered. This could indicate that four length class stanzas might exist. If these were indeed different stanzas, each class should display a unique coefficient. The length-mass relationship of these four stanzas was then individually plotted and a trend line fitted. The obtained results (Figure 5.28 to Figure 5.31 and Table 5.8) showed that for each of the suggested stanzas a distinct coefficient did exist and it was decided to regard each as a distinct growth stanza. It should be noted that the best fits were obtained in the two smaller length classes with R-squared values of 0.9709 and 0.9567, respectively. In the two longer length classes the fit was weaker but could still be regarded as good.

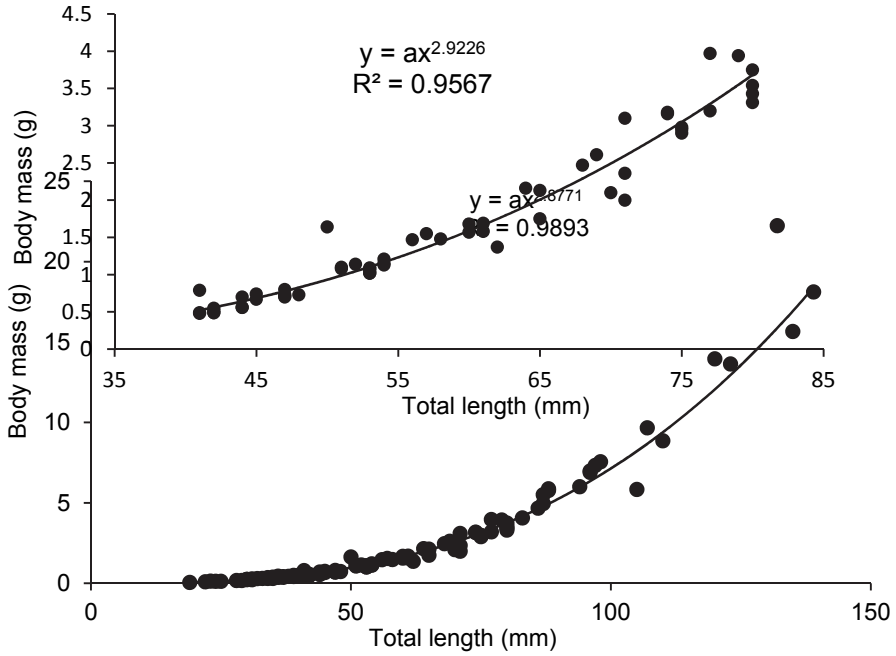


Figure 5.27. The length-mass relationship of *Glossogobius callidus* specimens collected in the Phongolo River system from April to November 2013.

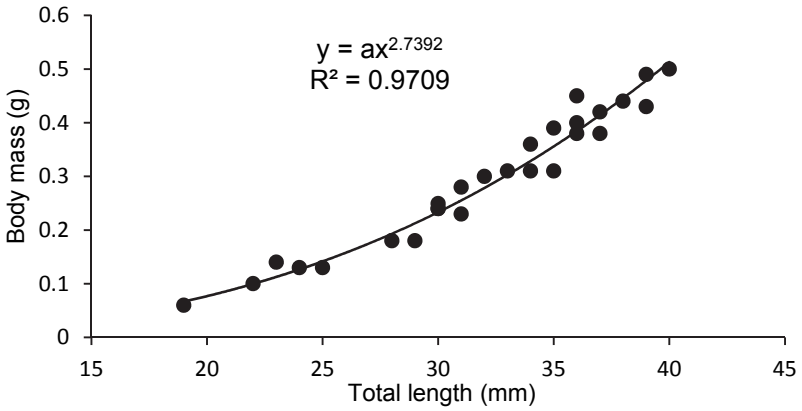


Figure 5.28. The length-mass relationship of *Glossogobius callidus* specimens in the total length class of 17 to 40 mm collected in the Phongolo River system from April to November 2013.

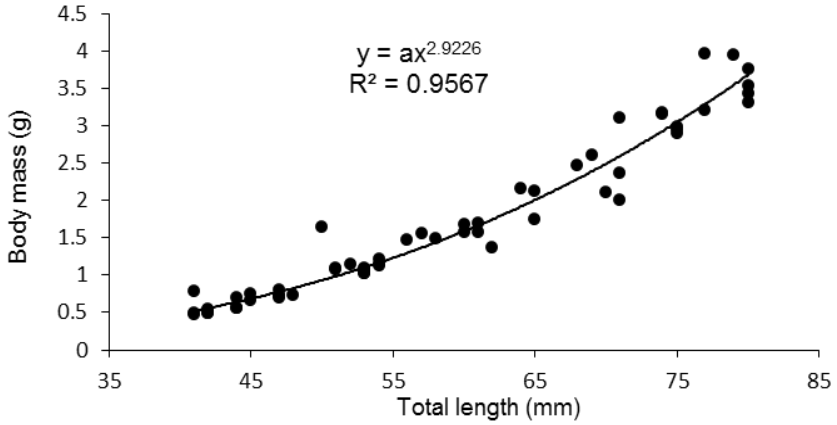


Figure 5.29. The length-mass relationship of *Glossogobius callidus* specimens in the total length class of 41 to 80 mm collected in the Phongolo River system from April to November 2013.

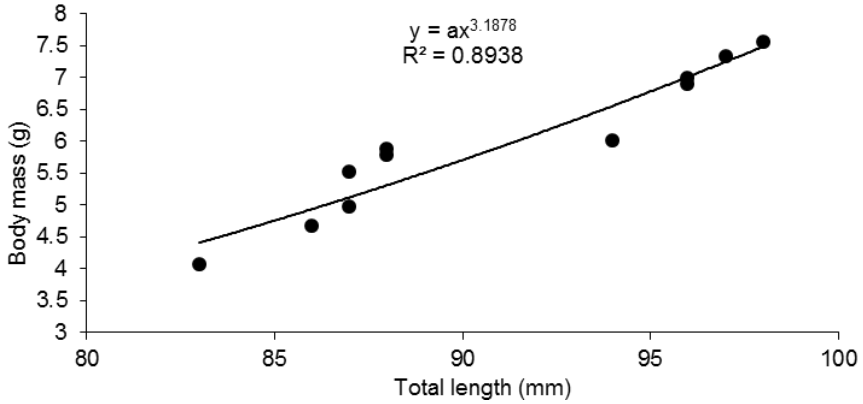


Figure 5.30. The length-mass relationship of *Glossogobius callidus* specimens in the total length class of 81 to 100 mm collected in the Phongolo River system from April to November 2013.

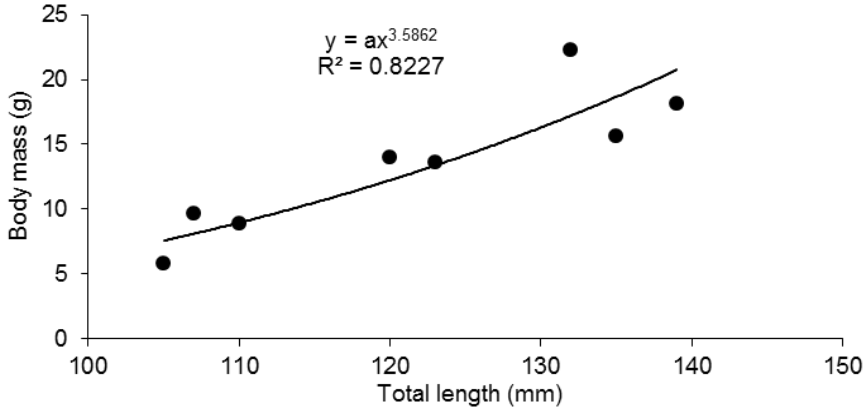


Figure 5.31. The length-mass relationship of *Glossogobius callidus* specimens in the total length class of >101 mm collected in the Phongolo River system from April to November 2013.

Table 5.8. The coefficients of *Glossogobius callidus* of different stanzas collected in the Phongolo River system from April to November 2013.

Class	Total length (mm)	Coefficient
1	17 to 40	2.7392
2	41 to 80	2.9225
3	81 to 100	3.1878
4	>101	3.5862

The spatial and temporal abundance of *Glossogobius callidus*

The total number of specimens of *G. callidus* is dominated by specimens of the first two total length (TL) classes throughout the surveys (Table 5.9). The largest number of specimens of *G. callidus* was collected during survey 2 and the highest number of specimens in the first two total length classes was collected in the same survey. The low number of specimens collected during the fourth survey should be noted. At all sites, specimens in the first two stanzas are the most dominant, with most specimens collected at Site 1 followed by Site 6; in addition, Site 3 had the lowest number of specimens collected with all stanzas included (Table 5.10).

Condition factor

Statistical analysis using Student's t-test showed that the calculated condition factor (CF) of the sites (Table 5.11) was not significantly different ($p<0.05$). Based on this finding it was decided to pool the data of the sites to determine the temporal changes in the CF. The highest average CF was observed during survey 1 and survey 4 while the averages were lower during survey 2 and survey 3 (Table 5.12). When graphically presented, a trend can be observed where the initial increase between the first and second survey is followed by a decrease in the third survey and an increase in the fourth survey (Figure 5.32). These changes in the CF are even more pronounced when the average of stanzas 3 and 4 is calculated (Table 5.12).

Table 5.9. The total number of *Glossogobius callidus* specimens in the four total length classes collected in the Phongolo River system from April to November 2013.

Total length classes (mm)	First survey April 2013	Second survey July 2013	Third survey September 2013	Fourth survey November 2013
17 to 40	1	8	17	1
41 to 80	17	29	7	6
81 to 100	4	5	2	0
>101	5	0	1	3

Table 5.10. The total number of *Glossogobius callidus* specimens in the four total length classes collected from the sites in the Phongolo River system from April to November 2013.

Total length classes (mm)	Site 1	Site 2	Site 3	Site 4	Site 6	Site 9
17 to 40	24	1	0	0	1	1
41 to 80	11	6	3	8	24	7
81 to 100	2	4	0	4	1	0
>101	3	2	0	1	1	2

Table 5.11. The condition factor of *Glossogobius callidus* in the different total length classes collected at different sites in the Phongolo River system from April to November 2013.

Classes (mm)	Site 1	Site 2	Site 3	Site 4	Site 6	Site 9
17 to 40	1.15	1.23	0.00	0.00	1.18	1.12
41 to 80	0.80	0.87	0.79	0.96	0.84	0.86
81 to 100	0.48	0.53	0.00	0.53	0.50	0.00
>101	0.15	0.19	0.00	0.17	0.13	0.21
Average	**0.65**	**0.70**	**0.79**	**0.55**	**0.66**	**0.73**

Table 5.12. The condition factor of *Glossogobius callidus* in the different total length classes collected during the surveys in the Phongolo River system from April to November 2013 (N = no fish).

Stanza no.	Stanzas (mm)	First survey April 2013	Second survey July 2013	Third survey September 2013	Fourth survey November 2013
1	17 to 40	1.12	1.12	1.17	1.23
2	41 to 80	0.85	0.85	0.84	0.90
3	81 to 100	0.53	0.51	0.52	N
4	>101	0.16	N	0.13	0.20
Average		**0.67**	**0.83**	**0.66**	**0.78**
Average of stanzas 3 and 4		**0.34**	**0.51**	**0.32**	**0.20**

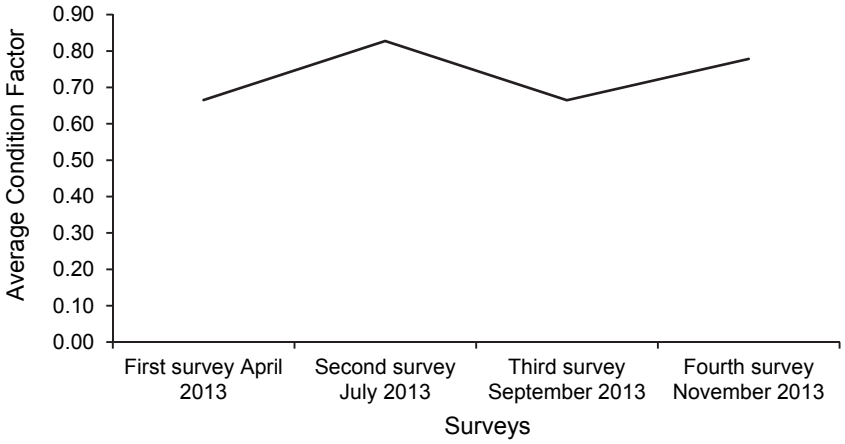


Figure 5.32. The average condition factor of *Glossogobius callidus* collected during the surveys in the Phongolo River system from April to November 2013.

Reproduction strategy

The gonadal development

Based on visual observation, specimens in the smallest stanza were observed to have only immature gonads, while immature and maturing gonads were observed in specimens in the second stanza, and maturing and mature gonads were observed in the third stanza. During surveys 1 and 2 the number of maturing and mature gonads was the highest with an increase that was recorded in survey 2. In survey 3 this number had decreased (Table 5.13).

Reproductive seasonality

The average gonadosomatic index (GSI) scores were low during survey 1 and survey 4 and were the highest during survey 2 (Tables 5.14 and Figure 5.33). Specimens in the second stanza were found to have the highest GSI scores (Table 5.14).

Table 5.13. Visual classification of gonadal maturity of female *Glossogobius callidus* of all total length classes collected in the Phongolo River system from April to November 2013 (1 = immature, 2 = maturing, 3 = mature and 4 = spent).

	First survey April 2013				Second survey July 2013				Third survey September 2013				Fourth survey November 2013			
	Classes of gonadal development															
Stanzas (mm)	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
17 to 40	1								1							
41 to 80	6		1		5	6	3			2	1		2			
81 to 100		1				1	2				1					
>101		4							1							
Total	**7**	**5**	**1**	**0**	**5**	**7**	**5**	**0**	**2**	**2**	**2**		**2**			

Table 5.14. The average gonadosomatic index scores of female *Glossogobius callidus* of all total length classes collected in the Phongolo River system from April to November 2013 (N = no fish).

Stanzas (mm)	**First survey April 2013**	**Second survey July 2013**	**Third survey September 2013**	**Fourth survey November 2013**
17 to 40	0.02	N	0.78	N
41 to 80	1.44	1.93	2.72	0.58
81 to 100	1.18	6.57	5.32	N
>101	0.35	N	0.35	N
Average	**0.75**	**4.25**	**2.29**	**0.58**

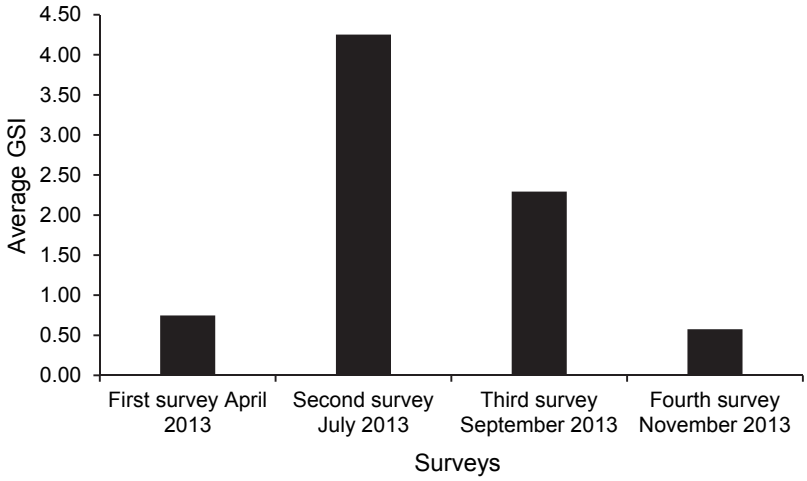


Figure 5.33. The average gonadosomatic index of female *Glossogobius callidus* collected in the Phongolo River system from April to November 2013.

Oocyte sizes

The measured oocyte diameters ranged from 0.05 mm to a maximum of 0.825 mm and Table 5.13 also shows that the largest, and potentially the most mature, oocytes were recorded in stanzas 2 and 3. In addition, Table 5.15 shows that the largest oocytes were observed in survey 2.

Table 5.15. The oocyte measurements of *Glossogobius callidus* of all total length classes collected in the Phongolo River system from April to November 2013.

Date of survey	**Stanzas (mm)**	**Size distribution (mm)**							**Minimum length (mm)**	**Maximum length (mm)**
		0 to .125	**to .250**	**to .375**	**to .500**	**to .625**	**to .750**	**to .875**		
April 2013	17 to 40	×							0.075	0.125
	41 to 80	×	×		×	×	×	×	0.050	0.775
	81 to 100		×	×	×	×			0.175	0.525
	> 101	×	×						0.075	0.250
July 2013	17 to 40	×	×						0.075	0.150
	41 to 80	×	×	×	×	×	×	×	0.100	0.800
	81 to 100		×	×		×	×	×	0.325	0.825
	> 101									

Table 5.15. (continued)

September 2013	17 to 40	×	×	×					0.125	0.325
	41 to 80	×	×	×	×	×	×	×	0.100	0.775
	81 to 100				×	×	×	×	0.425	0.800
	> 101	×	×						0.075	0.175
November 2013	17 to 40									
	41 to 80	×	×	×					0.075	0.275
	81 to 100									
	> 101	N	N	N	N	N	N	N	N	N

5.4 Discussion

5.4.1 Population structure and ageing

Ageing results suggest that the growth rate of *H. vittatus* was slower when compared to that of *H. vittatus* in the Okavango Delta (Gerber et al., 2009). Gerber et al. (2009) found that *H. vittatus* from the Okavango Delta grew at an average rate of 160 mm per year, compared to *H. vittatus* from the Nyamithi Pan which grew at an average rate of 33 mm per year. However, these data might not reflect the true growth curve of this population due to the high number of small *H. vittatus* caught. Very few adult *H. vittatus* were caught and this might have skewed the data to show slower growth rates. Badenhuizen (1967) demonstrated that the ability to catch *H. vittatus* decreases with decreasing stretched mesh sizes. Efficiency of the seine net was limited due to the fact that *H. vittatus* jumped over the net as the water became shallower despite the effort of lifting the nets higher. The presence of a large number of crocodiles limits the sampling efforts for *H. vittatus*, in that gillnets cannot be used. Males and females from the Nyamithi Pan had similar growth rates as those observed for *H. vittatus* from the Okavango Delta (Gerber et al., 2009). Although Gerber et al. (2009) showed that *H. vittatus* can grow up to 20 years old, the oldest *H. vittatus* caught during this study was six years old.

The initial growth of *O. mossambicus* is rapid with individuals reaching 100 mm within the first year. After the first year, fish grows at an average rate of 50 mm per year, till they reach a standard length of 300 mm. Fish that has a standard length of 300 mm is between the age of five and six years old. *Oreochromis mossambicus* from Nyamithi Pan grew slower (32.3 mm per year) when compared to other populations in Lake Chicamba (Mozambique) (± 50 mm per year) (Weyl & Hecht, 1998).

Male and female *O. mossambicus* have similar growth rates; however, males tend to grow bigger than females and reach maturity at 150 mm (SL). The largest male was 390 mm compared to the largest female of 290 mm. The oldest male and female collected were 10 years old with more of the males being present in this age group.

Based on the population structures, the majority of *O. mossambicus* caught in Nyamithi Pan were between six and 10 years old. These individuals were all sexually mature confirming that *O. mossambicus* does spawn in Nyamithi Pan. These species are known to breed in still-standing water (Skelton, 2001; Russell et al., 2012). The lack of younger *O. mossambicus* either indicates that they are preyed on by *H. vittatus* (which are abundant in this pan) or they move into the river to mature. There seems to be a gap in the population structure of fish ranging from 140 mm to 240 mm (three to five years of age). This might be due to the drought of 2008 when there was no water flowing into the Pongolapoort Dam (Chapter 3; Figure 3.3). This drought might have had a significant effect on the water level of Nyamithi Pan resulting in a loss of suitable breeding habitat for *O. mossambicus* during the summer months of 2008.

The initial rapid growth rate of *O. mossambicus* was observed in *C. rendalli* and individuals reached 100 mm (standard length) within the first year. The initial rapid growth of both these cichlid species was observed by Weyl and Hecht (1998) in Lake Chicamba (Mozambique). After the first year *C. rendalli* grows at an average length of ± 30 mm per year until they reach the age of five years. Male *C. rendalli* grows faster and larger than the females. The largest male *C. rendalli* was 315 mm (SL) compared to the largest female of 290 mm (SL), with the oldest male being nine years old and the oldest female eight years old.

Population structures indicate that Nyamithi Pan is mostly populated by large adult *C. rendalli* ranging between six and 10 years old. Very few small individuals were caught (Figure 5.17). There was a high abundance of fish within the 250 mm size class (five years) suggesting that during the drought of 2008 the *C. rendalli* population did not suffer from the drought to the same extent as *O. mossambicus.* Due to the high parasitic infestation (see below) in *O. mossambicus,* these species are already under pressure. The decrease in water level resulted in more stress (Bain et al., 1988; Arthington et al., 1999) that affected the population structure. This explains why the numbers of *C. rendalli* have increased significantly since 1994 (Merron et al., 1993; 1994a-f) (Chapter 7). However, the lack of smaller younger *C. rendalli* is a concern as the smaller *C. rendalli* falls prey to the large number of *H. vittatus* in the pan. Very few *C. rendalli* were found in the Phongolo River (Chapter 7). This might be attributed to unsuitable habitat, but if this is the case for the larger part of the river it might have a significant effect on the *C. rendalli* populations in the Phongolo River. Birds such as

the African fish eagle (*Haliaeetus vocifer*) also prey on fish and might possibly have an effect on the fish populations in Nyamithi Pan (Bouwman et al., 1990).

When comparing sexual maturity of *O. mossambicus* males collected from Nyamithi Pan, they were found to be smaller (160 mm SL) compared to the populations from a similar environment, Lake Chicamba in Mozambique (Weyl and Hecht, 1998) where maturity was reached at a total length of 251 mm.

5.4.2 Fish health assessment index (FHAI)

During the April 2013 survey, which is the high-flow period for this region, the condition factor of all the fish was higher compared to the low-flow period in September 2013. *Oreochromis mossambicus* from Nyamithi Pan were heavily infected (100%) with the parasitic copepod, *Lernaea cyprinacea*, which potentially contributed to the low condition factor (CF = 1.94 ± 0.19) when compared to the same species caught in a similar environment (CF = 4.09 ± 0.79) with no *L. cyprinacea* infection (Dalu et al., 2013). Very few *C. rendalli* or *H. vittatus* were infected with *Lernaea cyprinacea* or nematodes.

After the observation of the *L. cyprinacea* on the fish from the pan and their condition compared to the previous survey, a complete assessment of the health status of the fish according to Adams et al. (1993) was done during the September (2013) survey. When these fish where dissected, the heart cavity of the *O. mossambicus* was found to be severely infected with nematode parasites and the exterior of the fish was heavily infected with *Lernaea cyprinacea* (pers. observation) (Figure 5.34). No *Lernaea cyprinacea* were observed on the *C. rendalli* and very few nematodes were removed from this species. *Hydrocynus vittatus* were also infected with nematodes; however, no *Lernaea cyprinacea* were observed in this species.



Figure 5.34. A) A photograph of the heart of an *O. mossambicus* infected with nematodes, B) infection of *Lernaea cyprinacea* on *O. mossambicus* indicated by the white circles.

Based on the parasitemia, both these parasites seem to prefer the *O. mossambicus* as host. During the September (2013) survey (low flow) the *O. mossambicus* (K = 1.94 ± 0.19) and the *C. rendalli* (K = 3.85 ± 0.25) showed a lower condition factor when compared to *O. mossambicus* (K= 3.74 ± 0.40) and *C. rendalli* (K = 4.45 ± 0.59) collected during April 2013. The same trend was seen in the condition factor of *H. vittatus* (CF = 1.45 ± 0.23) in September 2013 compared to (K = 3.69 ± 0.39) in April 2013. The cause of this decrease can possibly be attributed to fact that the pan is cut off from the river during the low-flow season and thus formed a closed environment. The isolated pan becomes a breeding site for parasites with an increase in parasite concentration. It is well documented that there is a big fluctuation in salinity levels in Nyamithi Pan over different seasons (Heeg & Breen, 1982) and that regular flooding plays an important role in the flushing of this system, but it is not known what role this fluctuation and flushing plays in the health of the fish in the pan.

The HSI of *H. vittatus* during the April (2013) survey (0.67 ± 0.17) was slightly higher when compared to the September (2013) survey (0.41 ± 0.07). This falls within the ranges for *H. vittatus* from the Pongolapoort Dam (0.59 ± 0.81) (McHugh et al., 2011). The HSI of both cichlids was within the normal range (1.30 ± 0.30) (Van Dyk, 2007). The highest GSI values for *O. mossambicus* and *C. rendalli* were recorded during September at (0.79 ± 1.02) and (1.13 ± 1.20), respectively. This can possibly be because of the preparation for the breeding season in the summer months from mid-October to mid-February (southern hemisphere) (Weyl & Hecht, 1998; Skelton, 2001).

The GSI values of *H. vittatus* did not indicate that this species are preparing to breed; however, this may be due to the fact that the majority of the sample was small individuals. Based on the *H. vittatus* from the Okavango Delta, this species only reaches sexual maturity at the total length of 451 mm for males and 522 mm for females (Gerber et al., 2009). Due to the small sample size the sexual maturity of *H. vittatus* from Nyamithi Pan could not be determined; however, if this species were compared to that of the Okavango Delta they would not have been sexually mature yet at the average standard length of 195 (±128) mm.

The GSI values for both cichlids increased from April to September indicating that the gonads are developing during this period in order to breed during the summer months. Male *O. mossambicus* from Nyamithi Pan reach sexual maturity at an average standard length of ± 160 mm (Figure 5.23). This is slightly earlier than *O. mossambicus* populations from Lake Chicamba (Mozambique) which reached sexual maturity at the average total length of 251 mm for females and 223 mm for males (Weyl & Hecht, 1998).

Cichlids collected from Nyamithi Pan were larger and heavier than those found in the Phongolo River (Chapter 7). This confirms that Nyamithi Pan is populated by adult cichlids and the fact that their GSI values increase towards the summer months confirms that they use the pan as refuge for breeding purposes. No small cichlids where found in Nyamithi Pan which either means that they are preyed on by *Hydrocynus vittatus* (which are abundant in this pan) or they move into the river after spawning, or both. Although a few adult *H. vittatus* were caught, the majority were young fish this could be due to the low possibility to catch larger *H. vittatus*.

Based on the HAI scores of the three targeted species, *O. mossambicus* scored the highest (111 ± 10) followed by *H. vittatus* (42 ± 17) and *C. rendalli* (40 ± 10). *Oreochromis mossambicus* is under severe stress due to the high prevalence of parasites that seem to prefer this species to the other two mentioned species.

5.4.3 Histology-based assessment

The gill index of *O. mossambicus* (9.85) was significantly higher when compared to *C. rendalli* (5.1) ($p<0.05$). The liver index of *O. mossambicus* (6.4) was significantly higher than that of *C. rendalli* (4.5) ($p<0.05$). There was no significant difference between the kidney indices of these two species ($p>0.05$). There was no significant difference between the gonadal indices when the males and females from the two species were compared ($p>0.05$). However, the fish index score of *O. mossambicus* (19.25) was significantly higher when compared to that of *C. rendalli* (11.75) ($p<0.05$) (Table 5.5).

The histological assessment of *C. rendalli* indicated that the health status of these species is good as most of them fell within Class 1 indicating that they have normal tissue structures. All the indices calculated for *C. rendalli* were normal but *O. mossambicus* had the poorest scores of the three species. Overall, *O. mossambicus* was scored in Class 2 indicating moderate histological alterations. These alterations included: vacuolation of hepatocytes which can be linked to exposure to pesticides (Velmurugan et al., 2007), and hyperplasia and telangiectasia in the gill epithelium occurred which were also linked to exposure to pesticides (Velmurugan et al., 2007). It is known that DDT is being used in the Phongolo floodplain to control malaria (Bouwman et al., 1990) and DDT has an effect on the reproduction of fish (Zaroogian et al., 2001). Telangiectasia is associated with the breakdown of pillar cells (Van Dyk et al., 2009), whilst various circulatory disturbances were noted in the liver, which can be related to pathological conditions of blood and tissue fluid flow and regressive changes (McHugh et al., 2011). All the indices fell within Class 1 with the exception of the gill index that fell in Class 2.

The same histological alterations found in *O. mossambicus* were observed in the organs of *H. vittatus* but were not as severe as *O. mossambicus*. These histological alterations can be linked to the use of pesticides in the surrounding area and that biomagnification occurs as pesticides move up the food chain. The indices of *H. vittatus* from Nyamithi Pan indicate that their gills have more alterations when compared to the *H. vittatus* from Pongolapoort Dam (McHugh et al., 2011). However, the fish index suggests that *H. vittatus* from Nyamithi Pan is healthier in that they have fewer alterations overall when compared to the *H. vittatus* from Pongolapoort Dam (McHugh et al., 2011).

5.4.4 *Glossogobius* breeding strategies

The results of this project indicate that *G. callidus* breeds in spring in the period between July and September. This conclusion is based on the fact that the GSI scores were the highest in the July survey, followed by a decline to the low scores in the third survey during September (Figure 5.33). These results are supported by the gonadal classification based on visual observation (Table 5.13), the calculated CF scores (Table 5.12) and classification of the oocyte sizes (Table 5.15). Figure 5.33 further indicates that the spawning period could be regarded as extended since relatively high GSI scores were still observed in September but had definitely declined by November.

It should be noted that this extended spawning period coincided with a period in which no flood releases occurred and could be a contributing factor in the adaptive success of the species. It is furthermore shown that the species reaches sexual maturity when the females are relatively small (>40 mm) which would allow breeding to occur at a young age.

5.5 Conclusion

Both indigenous cichlid species breed in standing water (Skelton, 2001) and since the pans outside of the Ndumo Game Reserve are heavily utilised by local communities, the pans in the protected area serve as very important refugia (Heeg et al., 1980). Based on the results presented, it is evident that these two species do use Nyamithi Pan as a refuge area to breed in. The community structures of the pan indicate that it is largely populated by cichlids between the ages of four to 10 years old. Very few young cichlids were found in the Nyamithi Pan and could be a cause of concern due to the pressure specifically on the adult fish *O. mossambicus* (e.g. crocodiles, tigerfish and parasites). The majority of *H. vittatus* were small and this can be attributed to the fact that this species is increasingly difficult to sample as they grow bigger. More sampling is needed to understand the biology and ecology of this species from Nyamithi Pan.

Results of the macro-level and histological health assessments indicate that the *O. mossambicus* in the Nyamithi Pan is in poor health and thus under major stress. High infestations of internal and external parasites make a major contribution to the deteriorating condition factor of this species. These fish also experience additional pressure due to predation by crocodiles and the piscivorous *H. vittatus*. *Coptodon rendalli* seem to be in a much better condition than *O. mossambicus* and do not suffer from the high parasitic infestations observed in *O. mossambicus*. However, what might be of concern is the fact that very few small *C. rendalli* specimens were caught in the Nyamithi Pan and the Phongolo River during 2012-2014. This might mean that the recruitment of this species is under pressure. If this is the case in large stretches of the Phongolo River it might be a cause for concern as *C. rendalli* forms an important part of the subsistence fishery in this region (see Chapter 8, Section 8.2).

It is evident that all the species in the Nyamithi Pan, especially the cichlids, are very dependent on the water flow and its associated water level. The drought of 2008 had a significant effect on the population structures of both these species. The important role played by the flood regime in these economically important species should be emphasised. It is well-documented that there is a huge fluctuation in salinity levels in the Nyamithi Pan over different seasons (Heeg & Breen, 1982) and that regular flooding plays an important role in the flushing of this system, but it is not known what role this fluctuation and flushing plays in the health of the fish in the pan. It is thus important that future studies should focus on whether the poor health observed in *O. mossambicus* is related to irregular controled flooding or the presence of the alien parasite, *L. cyprinacea*.

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6 BIOACCUMULATION AND BIOMAGNIFICATION OF DDT AND OTHER RELEVANT ORGANIC POLLUTANTS AND POTENTIAL IMPACTS THEREOF ON THE LOWER PHONGOLO RIVER AND FLOODPLAIN AND THE ASSOCIATED RISK OF EXPOSURE TO THE LOCAL COMMUNITIES

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6.1 Introduction

Immediate recognition of the toxic effects of pollutants and their derivatives on the fauna of aquatic water systems is not always possible when initial exposure occurs (Van der Oost, 2003). Generally, toxic effects only become evident through long-term exposure and accumulation of the pollutant. Since the majority of contamination occurs in small undetectable doses, these delayed reactions by organisms only occur when the contamination level is not very high. The progression from exposure to observable toxic effect where a toxicant ascends from cellular to population level in exposed and susceptible species has led to the use of changes in biomarker values to assess adverse toxicant effects (Van der Oost, 2003).

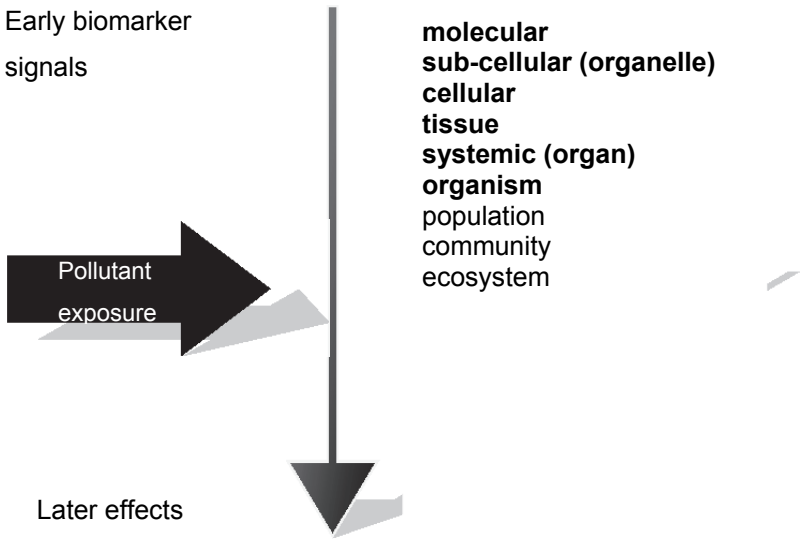


Figure 6.1. Figure modified from Van der Oost (2003) indicating the progression of responses to contaminant stress.

Biomarkers are defined as measuring parameters reflecting interactions between a specific biological structure and stressful environmental factors, which could be chemical, biological or physical (De la Torre et al., 2007). Biomarkers provide quantitative and qualitative information expressing biological and biochemical effects of exposure. To observe biological changes caused by pesticides on the molecular level is advantageous, since the effect thereof on the survival and long-term effect on the health of the organism can be predicted. The impact of the levels and frequency of pesticide application on organismal health can be assessed by means of regular biomarker analysis. The findings are then available for the management of pesticide control programmes.

Biomarker analyses provide an early warning detection mechanism where information on the action and effect of a particular toxicant on the cellular level is valuable. Biomarkers assist in the early detection and prevention of future detrimental impacts and are useful in establishing the factor responsible for the initial exposure. Most importantly, biomarkers assist in the prevention of impending adverse effects (Chapman, 1992).

Biomarkers of exposure were used to determine measurable toxicant levels or characteristic cellular interactions within an organism as a result of contaminant or metabolite presence. Furthermore, biomarkers of effect were selected that show biochemical or physiological alterations quantifiable within an organism as a direct result of xenobiotic exposure and interactions.

The liver was used to measure biomarkers of effect and exposure. As the site of major metabolic activities, the liver plays a significant role in the accumulation, biotransformation and excretion of toxicants (Braunbeck et al., 1998).

The specific biomarkers used in this study were selected for their reliability, comparability and success in previous studies on freshwater fish. Biomarker selection was also aimed to reflect the presence of a variety of contaminating compounds and their resultant biological effects.

6.1.1 Bioaccumulation of POPs

The study area is defined as an endemic intermediate to low-risk malaria area (McHugh et al., 2011). Spraying in this area takes place for the purpose of malaria vector control, starting in January and extending through to the end of March (Bouwman et al., 1990). The pesticide used for the application of indoor residual spraying is technical grade dichlorodiphenyltrichloroethane (DDT). DDT was used as a stock remedy and was the preferred pesticide for many South African farmers until it was banned in 1974. This banning led to a large decline in its overall use as a general

pesticide (Van Dyk et al., 1982). The use of DDT continued informally in the agricultural sector, but mainly as part of malaria control programmes, until it was completely banned by the Stockholm Convention on Persistent Organic Pollutants in 1996 (Wells & Leonard, 2006). Substituting pyrethroid pesticides for DDT to control the malaria vector resulted in an increase in deaths related to and caused by malaria. This increase has led to the reintroduction of DDT as the principal malaria vector control pesticide and this has been supported by the World Health Organization (WHO) since 2006 (Ansara-Ross et al., 2012).

Although DDT is the main focus of this study, levels of other organochlorines are also used within this area and have been found within the analyzed samples. These OCPs include lindane (γ-HCH) and its by-products (α-HCH, β-HCH), trans-chlordane and trans-nonachlor (chlordane) as well as hexachlorobenzene (HCB). Both lindane and chlordane were found in smaller quantities in whole fish from Hartbeespoort and Voëlvlei Dams (Greichus et al., 1977), but have not been reported in the Phongolo River system. Lindane and chlordane are insecticides which are used for the management of crops. Control of lice and scabies with lindane shampoo is still common, even after its ban in agricultural use (Engeler, 2009). Chlordane is used for disease control in citrus plantations (Quinn et al., 2001). HCB is another persistent organic pollutant which was banned by the Stockholm Convention on Persistent Organic Pollutants and was previously used as a fungicide. Application of this fungicide was mainly to seeds for planting, and levels have been found in human breast milk (Jensen & Slorach, 1991). Only limited reports are available on levels of HCBs within the Phongolo River system. Monitoring programmes in developing countries do not accurately keep track of pesticides that are used, even if they are banned substances, and this means that contamination may still occur due to their continued use (Ansara-Ross et al., 2012).

6.1.2 Biomarkers of exposure

Acetylcholinesterase (AChE)

Acetylcholinesterase is an enzyme mainly found in the nervous tissues of most vertebrates, yet within fish it is known to have a greater presence within the liver (Leticia & Gerardo, 2008). The presence of low concentrations of organophosphate and carbamate pesticides results in AChE inhibition (Guilhermino et al., 2000). Acetylcholinesterase becomes a reliable indicator as a result of organophosphate inhibition being so distinct in yielding concentration-dependent inhibition to exposure (Brown et al., 2004).

Cytochrome P450

Cytochrome P450 is one of the most important phase 1 biotransformation enzymes of the liver playing a crucial role in detoxification where the haem iron is used in oxidising xenobiotics into water-soluble forms (Whyte et al., 2000; Pérez-López, 2002). Additional properties of the Cyt P450 monooxygenase are reactive oxygen species (ROS) formation during oxidation processes and a stimulatory activity caused by DDD and DDE presence (Zapata-Perez et al., 2000; Riffat & Ahmad, 2006). Cyt P450 has widely been used as a biomarker due to its detection simplicity and high sensitivity (Orrego et al., 2005; Lavado et al., 2006).

Metallothionein (MT)

Metallothioneins are cysteine-rich proteins mainly induced in the presence of both physiological metals (copper and zinc) and the xenobiotic metals, i.e. cadmium, copper and mercury (Klaassen et al., 1999; Acker et al., 2005). As biomarkers they are effective in measuring metal levels in exposed organisms, yet in cases of overexposure, rapid increases in MT production can eventually lead to systemic damage (Krishnakumar et al*.,* 1994). A few other MT functions include: cellular protection from superoxide and hydroxyl radicals that bind to MT cysteine residues and an involvement in metal-ion donation for metalloprotein synthesis (Berger et al*.*, 1995; Amiard et al., 2006).

6.1.3 Biomarkers of effect

Oxidative stress is a result of over-production of reactive oxygen species (ROS), the destructive by-products of metabolic oxidative reactions. Organisms have complex defence systems to ensure their integrity; the balancing act that those **systems** perform is called **homeostasis.** Yet on occasion that balance can be affected by external or internal factors generating reactive ions such as hydroxyl radicals ($^{\bullet}HO$), hydrogen peroxide (H_2O_2) and superoxide anion (O_2^-) that affect organism health (Bagnyukova, 2005; Amiard, 2006). Five specific biomarkers were selected to determine the level changes in the anti-oxidants that protect the liver and kidney against oxidative stress.

Catalase (CAT)

Catalase is a 4-chain polypeptide containing a porphyrin haem (iron) where H_2O_2 is bound and decomposed to H_2O and O_2 to prevent tissue damage (Gaetani et al., 1996). Demonstrating observably low CAT levels can be an indication of disease in an individual. Catalase is a phase 1 protein, the first line of defence from ROS and is inhibited by metals such as copper and chromium (Lionetto et al., 2003).

Lipid peroxidation (MDA) assay

Lipid peroxidation is the oxidative degradation of lipids in the cell membrane; the end-products are reactive aldehydes, such as malondialdehyde (MDA), which is measured as a biomarker of heavy metal and trace organic effects (Lushchak et al., 2009; Solè et al., 2010). Malondialdehyde is a highly reactive product which can either bind to DNA forming DNA adducts or bind to protein adducts and become a highly destructive modified protein which leads to DNA and cell membrane destruction (Stocker & Keaney, 2004; Dalle-Donne et al., 2006).

Protein carbonyls (PC)

Protein carbonyls are products of amino residue oxidation measured as a biomarker of exposure to pesticides including deltamethrin, endosulfan and paraquat (Castegna et al., 2003; Parvez & Raisuddin, 2005). Protein carbonyls are chemically stable making them reliable and useful for laboratory analysis and storage (Dalle-Donne et al., 2006).

Superoxide dismutase (SOD)

Superoxide dismutase is essential in phase 1 of defence to toxicant exposure where SOD as an oxidoreductase enzyme converts the superoxide anion (O_2^-) to molecular oxygen (O_2) and H_2O_2 which is further converted to H_2O and O_2 by catalase (CAT) (Pandey et al., 2003; Radovanović et al*.,* 2010). When the SOD level in organisms is elevated due to high metal presence, it tends to bind to citric acid cycle enzyme aconitase causing it to release Fe, which has highly toxic effects especially on the metabolism process (Ferreira et al., 2007).

Glutathione (GSH)

Glutathione is a phase 2 biotransformation enzyme mainly found in the mitochondria indicating metal contamination (Briviba et al., 1993). As an enzyme it is a cysteine-rich tripeptide whose main functions include: 1) scavenging for H_2O_2 and free radicals; 2) repairing ROS damage; 3) xenobiotic detoxification by conjugation with GST; and 4) repairing DNA damage with N-acetyl cysteine (Meister, 1985; Kovačević et al*.,* 2008). Glutathione presence is crucial in ROS protection and cellular repair. During oxidative stress, reduced glutathione (GSH) is transformed to oxidised glutathione (GSSG) and the ratio of GSH to GSSG is a useful indicator of oxidative stress (Slivka et al., 1987).

Cellular energy allocation (CEA)

Energy reserves are the perfect balance between energy acquired from food and energy utilized during reproduction, growth and maintenance. It is only during stressful conditions such as climate change, injury, disease and xenobiotic exposure when an organism increases the amount of energy

expended in order to cope with the extreme conditions or to compensate for energy lost (Smolders et al., 2003). Cellular energy allocation is a simple, reliable and sensitive bioassay reflecting the presence and effects stress has on energy reserves (De Coen & Janssen, 1997).

6.1.4 Tissue cultures and cell-line responses

Genetically modified cell-lines to detect and semi-quantify (anti-)androgen, (anti-) oestrogen active compounds as well as those that bind to the aryl hydrocarbon receptor (AhR), were used to determine the level of contamination in the water and sediments at the same sites where the fish were sampled for organochlorine pesticides (OCP) accumulation. The AhR is a cytoplasmic receptor acting as a ligand-activated transcription factor that is involved in the regulation of a number of genes (Hahn, 1998).

6.2 Materials and methods

Three sampling surveys were carried out in November 2012 (post artificial flooding), April (high flow) and September 2013 (low flow) where *Oreochromis mossambicus* and *Clarias gariepinus* were sampled.

6.2.1 Sampling sites

- Phongolo River, pump station and adjacent pans (Sites 3, 8 & 9)
- Nyamithi Pan (Sites 7 & 10)
- Usutu River (Site 6)
- Nomaneni Pan (Site 11)

O. mossambicus (O. moss) was sampled from Sites 8 and 9 in November 2012, April 2013 and September 2013 and Site 6 (Usutu River) was sampled only in April 2013. Samples of *C. gariepinus* (C. gar) were taken from Sites 8 and 9 during both the November 2012 and April 2013 sampling periods. Sampled fish were temporarily kept in containers provided with battery-operated air blowers to supply oxygen to the fish during transport back to the field laboratory at the camp site for dissection.

6.2.2 Water sample collection

For cell culture analysis

Duplicate samples were collected in 1 L Schott bottles (pre-cleaned with methanol (MeOH)), by allowing water to flow into the opened container. In order to stabilise the target compounds, the pH of these samples was adjusted to between 2 and 3 with hydrochloric acid, t before storing in the dark at 4°C (De Jager et al., 2012).

Water extraction for evaluating hormonal activity

The water samples were pre-filtered and the target compounds eluted from the samples employing the methods described by De Jager et al. (2012).

6.2.3 Sediment sampling

All equipment was rinsed with analytical grade acetone and hexane after washing and rinsing with distilled water after each sample to remove polar and apolar contaminants, respectively. Only instruments made of metal were used to prevent contamination of samples with constituents from plastic containers (US EPA, 1994). The utensils were rinsed with river/pan water between consecutive sampling sites. The top 5 cm sediment at various intervals within a 5 m radius was scooped up with a metal cup and thoroughly mixed in a stainless steel bowl from where duplicate samples were transferred into 250 mL high density polyethylene (HDPE) bottles. The samples were protected from UV radiation breakdown as well as microbial deterioration by transporting and storing the samples at -20°C (Hilscherova et al., 2003).

Sediment extraction for evaluating hormonal activity

Thawed and air-dried sediment samples were ground and sieved through 0.5 mm mesh size to obtain a homogeneous sample. Standard techniques were employed during the extraction procedure (US EPA, 1996; McCant et al., 1999).

Sediment extraction for evaluating Ah-receptor binding activity

In general, the principles for this sample preparation were similar to the methods used in the evaluation of hormonal activity as previously described by Bernsmann and Fürst (2004). Also, two separate extracts were prepared from the same sample to distinguish between the persistent Ah-R ligands, e.g. dioxins and dioxin-like PCBs, and the non-persistent ones (US EPA, 1996)

6.2.4 Tissue cultures: maintenance and bioassay

Tissue culture of cryopreserved cells was started by placing cells in tissue culture dishes filled with the cell line's respective nutrient media at 37°C in a humidified incubator. The methods used for tissue culture maintenance and bio-assay were standard and obtained from the literature (Finney, 1978; Mosmann, 1983; Koistinen, 1998; Hilcherova et al., 2001; Villeneuve et al., 2002).

6.2.5 Fish tissue sampling

The liver was removed, the mass determined with an electronic scale and the mass recorded. It was stored in Hendrickson's buffer (Wepener et al., 2005) and put into a container with liquid nitrogen. The liquid nitrogen preserves the tissue and prevents degeneration and the buffer stops any enzyme activity taking place within the tissue. Muscle tissue from the lateral sides of the fish was removed, put into Hendrickson's buffer before storing in liquid nitrogen.

Upon arrival at the laboratory, field samples were transferred to a laboratory freezer set at -80°C until further analysis. Prior to analysis samples were thawed and homogenized in homogenising buffer.

6.2.6 OCP analysis

All the fish muscle tissue samples were analysed for OCP levels by students at the Environmental Toxicology Laboratory, School of Veterinary Medicine, Hokkaido University, Sapporo, Japan. The procedures followed, with some modifications, and standards used are according to Yohannes et al. (2013). The standard mixture containing DDT, HCH, chlordane, the "drin" compounds (aldrin, dieldrin), heptachlor and HCB at a concentration of 10 µg/mL was used. The solvents used were hexane and acetone in a 3:1 ratio (extraction solvent) as well as dichloromethane and hexane solution at a ratio of 2:7 (clean-up solvent). Fish tissue samples (10 g wet weight) were homogenized in anhydrous sodium sulphate and analysed.

Analysis of organochlorine pesticides (OCPs) was carried out with a gas chromatographer (GC) equipped with ^{63}Ni electron capture detector (GC-ECD: Shimadzu GC-2014, Kyoto, Japan). An ENV-8MS capillary column (30 m length×0.25 mm i.d., 0.25 µm film thickness; Kanto Chemical Co., Japan) was used for separation. A splitless mode was used to inject 1 µL of each sample (Yohannes et al., 2013).

Quality control during the analysis of OCPs was done where a comparison between the retention times of corresponding standards was used to identify the specific OCPs. The quantification of OCP

levels was obtained through creating multi-level calibration curves and through this linearity $R^2 \geq 0.995$ was achieved. Procedural blanks and spiked blanks were used for quality control, which showed that blank samples had no presence of the target metabolites, but that the percent recovery of the spiked sample was 90% to 105% (Yohannes et al., 2013).

Ratios of p,p'-DDE vs. p,p'-DDT were calculated in order to determine whether the DDT spraying activities in the study areas are due to recent or historical events. Low ratio values show that more recent spraying has taken place and higher values indicate the presence of higher levels of p,p'-DDE which means that a degree of breakdown has occurred and that spraying is therefore of a more historical nature. The breakdown ratios of DDT are generally in the following percentages: 75% p,p'-DDT, 15% p,p'-DDT, 5% p,p'-DDE and <5% other metabolites (Yang et al., 2005).

6.2.7 Biomarker analysis

Biomarker activities were calculated per mg of protein per sample, protein content was determined by using the Bradford protein assay (Bradford, 1976). This method is based on the principle of protein-dye binding (using the Bradford reagent) to measure the total protein concentration in a sample. Protein standard solutions were prepared using BSA (bovine serum albumin) During all procedures, 0.2 g of fish liver tissue was homogenised in specified buffer solutions, samples were kept continuously on ice and readings were taken in triplicate and obtained on an automated microplate reader (FLx800™ Multi-Detection Microplate Reader, BioTek instruments, USA) at respective wavelengths. Any deviations from the information provided will be specified where applicable.

Biomarkers of exposure

Acetylcholinesterase

The acetylcholinesterase (AChE) assay was performed following a modified Ellman procedure (Ellman et al., 1961). Thawed fish sample tissue was homogenised in a Tris/sucrose buffer at pH 7.4 (1:5 ratio) centrifuged at 9 500 g for 10 min at 4°C and prepared for concentration determination with the microplate reader.

Cytochrome P450

Fish tissue was homogenised in general homogenising buffer (ratio 1:10) and the sample was processed by means of a Demethylating Fluorescent Activity Kit (Arbor Assays, K011-F1) to determine cytochrome P450 (Cyt P450) activity. First, standards were prepared with assay buffer and a formaldehyde stock solution. Thereafter the procedure for sample preparation was followed

and the fluorescence intensity was measured using the FLx800™ Multi-Detection Microplate Reader (Synergy HT; BioTek Instruments, USA) at an excitation of 450 nm and an emission of 510 nm.

Metallothionein

Protein induction of metallothionein (MT) was determined by using a modified procedure of Viarengo et al. (1997). Sample tissue was homogenised in MT Tris/sucrose buffer (ratio 1:3) and after preparation according to the published procedure the samples were transferred to the microplate and read in the microplate reader after 15 minutes incubation.

Biomarkers of effect

Catalase

A modified Cohen et al. (1970) protocol was utilized to determine catalase induction. Fish tissue was homogenised in general homogenising buffer (pH 7.4) in a ratio of 1:10. The homogenate was prepared using the prescribed procedure and readings from the microplate reader were used to calculate the catalase levels.

Lipid peroxidase

Lipid peroxidation was analysed by determining malondialdehyde content by means of a modified procedure of Ohkawa et al. (1979). Tissue was prepared by homogenising it in Tris/sucrose buffer, followed by the procedure as described by Ohkawa et al. (1979); thereafter samples were transferred to microplates and read on the microplate reader.

Protein carbonyls

In order to determine protein degradation, protein carbonyl content was calculated according to a modified procedure of Parvez and Raisuddin (2005). In preparation, fish tissue was homogenised in general homogenising buffer (ratio 1:10) and centrifuged at 10 500 g for 10 min at 4°C. The standards were prepared with bovine serum albumin and general homogenising buffer and were read immediately after reading the sample plate for a standard curve to be calculated.

Superoxide dismutase

Superoxide dismutase (SOD) was determined according to a modified method of Greenwald (1989). Fish tissue was homogenised in general homogenising buffer (ratio 1:10) and centrifuged at 10 500 g for 10 min at 4°C. The prepared samples were read on the microplate reader at 405 nm in the dark.

Glutathione

Reduced glutathione activity was determined according to a modified glutathione fluorometric assay of Cohn and Lyle (1966). Sample tissue was prepared by homogenising it in general homogenising buffer (ratio 1:10) before centrifuging at 10 500 g for 10 minutes at 4°C. Standards were prepared with Reduced Glutathione Standard Solution and were read separately directly after reading the sample plate for the standard curve to be calculated.

Cellular energy allocation

Cellular energy allocation (CEA) is calculated by the difference between Ea (energy available) and Ec (energy consumed). Ea was determined by calculating its individual energy fractions where glucose, lipid and protein contents were determined and the resultant values were combined to determine the total energy available. Resultant energy fractions were converted to energy equivalents by means of enthalpy of combustion values of De Coen and Janssen (1997). These values included 39 500 mJ/mg lipid, 24 000 mJ/mg protein and 17 500 mJ/mg glycogen. The EC values were calculated by means of a theoretical stoichiometric relationship where for each 2 µmol of formazan formed, 1 µmol of oxygen is consumed. This oxygen is then converted to energy equivalents using the mean oxyenthalpic equivalent for an average lipid, protein and carbohydrate mixture of 484 kJ/mol O_2. The final cellular energy allocation is calculated as follows:

$$\mathbf{CEA = E_A - E_C}$$

$$\mathbf{E_A = E_{glucose} + E_{lipid} + E_{protein}}$$

$$\mathbf{E_C = E_{ETS}}$$

$$\mathbf{Energy = mJ/g}$$

Samples for both Ea and Ec procedures were prepared by homogenising 0.2 g of fish muscle in 400 µL of ETS homogenising buffer (ratio 1:5). Samples were then separated with 100 µL of homogenate diluted with deionised water for the Ea procedures and 100 µL of homogenate diluted with ETS homogenising buffer for Ec procedures (De Coen & Janssen, 1997).

6.2.8 Statistical analysis

An SPSS Statistical Analysis Program 21 was utilized to analyse spatial and temporal variations by means of a one-way ANOVA. Individual sites were used as variables and the resulting data were tested for normality and homogeneity of variance. Post-hoc multiple site comparisons were performed on resulting data which were log-transformed and analysed by means of Tukey's test to determine values which significantly differed; the probability of significance was established at

p<0.05 (Zar, 1996). GraphPad Prism was employed to represent finalised mean and SEM results in bar graph format with error bars included to indicate standard error.

6.3 Results

The results obtained are presented in graphs and tables. Tables 6.1-6.6 include biometric measurements obtained from the target species sampled at the different sites in November 2012, April 2013 and September 2013. Tables 6.1-6.3 present the data for *O mossambicus* and *C. gariepinus* and Tables 6.4-6.6 present data for *H. vittatus* and *S. zambezensis*. Figures 6.2-6.4 reflect results obtained from the biomarker responses of the four target species in the study at the different sites in November 2012, April 2013 and September 2013. Table 6.7 presents **r**esults for the oestrogen activity assay for water and sediment sampled in November 2012 and April 2013. Table 6.8 presents the results for the AhR activity assay, the non-acid-washed extracts (all ligands) and the acid-washed extracts (persistent ligands) for November 2012 and April 2013. Table 6.9 presents the OCP values for *O. mossambicus and C. gariepinus* while Table 6.10 shows the OCP values for *H. vittatus* and *S. zambezensis.*

6.3.1 Fish and tissue sampled

Table 6.1. Biometric data (mean ± SE) of the mass, length and liver mass of *O. mossambicus* and *C. gariepinus* sampled from the Phongolo River from November 2012 to September 2013.

Sampling survey	Fish species	Mass	Length		Liver mass
		(g)	Total (mm)	Standard (mm)	
November 2012	*O. moss* (n=10)	273 ± 221	16.3 ± 1.5	13.1 ± 1.3	0.71 ± 0.12
	C. gar (n=10)	549 ± 264	30.1 ± 5.31	27 ± 4.8	3.9 ± 2.11
April 2013	*O. moss* (n=10)	69.8 ± 24.2	158.8 ± 11.4	125 ± 9.2	1.45 ± 0.64
	C. gar (n=10)	207 ± 25.8	295 ± 11.7	262 ± 10.7	1.34 ± 0.22
September 2013	*O. moss* (n=21)	116 ± 21.7	178 ± 9.3	143 ± 7.8	1.38 ± 0.48
	C. gar (n=1)	120	265	230	0.857

Table 6.2. Biometric data (mean ± SE) of the mass, length and liver mass of *O. mossambicus* and *C. gariepinus* sampled from the Nyamithi Pan from November 2012 to September 2013.

Sampling survey	Fish species	Mass	Length		Liver mass
		Total (g)	Total (mm)	Standard (mm)	(g)
November 2012	*O. moss* (n=10)	740 ± 120	30.3 ± 1.74	25.2 ± 1.5	4.6± 1.12
	C. gar (n=10)	1378 ± 265	47.6 ± 4.74	42.2 ± 3.82	7.2 ± 1.78
April 2013	*O. moss* (n=15)	468 ± 72	283 ± 18	221 ± 13.1	4.05 ± 0.63
	C. gar (n=10)	3688 ± 673	763 ± 76	664 ± 66	22 ± 4.6
September 2013	*O. moss* (n=26)	683 ± 659	302 ± 297	245 ± 240	7.24 ± 7.08
	C. gar (n=15)	1852 ± 418	556 ± 58.3	481 ± 47.6	12 ± 276

Table 6.3. Biometric data (mean ± SE) of the mass, length and liver mass of *O. mossambicus* and *C. gariepinus* sampled from the Usutu River during April 2013.

Sampling survey	Species	Mass	Length		Liver mass
		Total (g)	Total (mm)	Standard (mm)	(g)
April 2013	*O. moss* (n=10)	44 ± 9.33	135 ± 6.32	104 ± 5.09	0.30 ± 0.03

Table 6.4. Biometric data (mean ± SE) of the mass, length and liver mass of *H. vittatus* (*H. vitt*) and *S. zambezensis* (*S. zam*) sampled from the Phongolo River (Site 7) during this study.

Sampling survey	Species	Mass	Length		Liver mass
		Total (g)	Total (mm)	Standard (mm)	(g)
November 2012	*S. zam* (n=10)	182 ± 68.2	158 ± 3	136 ± 4.3	
April 2013	*S. zam* (n=15)	50 ± 5.9	160 ± 6	124 ± 4.3	0.8 ± 0.1
	H. vitt (n=9)	58 ± 28	175 ± 22.5	50 ± 17	0.51 ± 0.2

Table 6.5. Biometric data (mean ± SE) of the mass, length and liver mass of *Hydrocynus vittatus* (*H. vitt*) and *Synodontis zambezensis* (*S. zam*) sampled from the Nyamithi Pan (Sites 6 and 10) during this study.

Sampling survey	Species	Mass	Length		Liver mass
		Total (g)	Total (mm)	Standard (mm)	(g)
November 2012	*S. zam* (n=10)	80 ± 5	166 ± 2.6	194 ± 3.5	
	H. vitt (n=10)	480 ± 97	28 4 ± 29	352 ± 34	
April 2013	*S. zam* (n=7)	72 ± 17.6	174 ± 12.2	138 ± 9.2	1.2 ± 0.25
	H. vitt (n=11)	688 ± 280	367 ± 41	289 ± 34	4.2 ± 1.53
September 2013	*S. zam* (n=20)	56 ± 7.9	173 ± 5.3	138 ± 4.6	0.87 ± 0.13
	H.vitt (n=19)	128 ± 29	297 ± 10.2	232 ± 8.2	1 ± 0.13

Table 6.6. Biometric data (mean ± SE) of the mass, length and liver mass of *Hydrocynus vittatus* (*H. vitt*) and *Synodontis zambezensis* (*S. zam*) sampled from the Nomaneni Pan (Site 12) during this study.

Sampling survey	Species	Mass	Length		Liver mass
		Total (g)	Total (mm)	Standard (mm)	(g)
April 2013	*H. vitt* (n=7)	87 ± 4.9	218 ± 3.5	164 ± 3.1	0.88 ± 0.08

6.3.2 Cell cultures

Androgen activity

None of the extracts tested, either from water or sediment, elicited any response in the luciferase assays (MDA-kb). This was true for both sampling events. None of the extracts of the first sampling event were cytotoxic, therefore the negative results were due to a lack of androgen receptor ligands. However, some of the extracts from water and sediment samples were observed to be slightly cytotoxic.

Oestrogen activity

More oestrogen than androgen activity was observed among the samples. Figure 6.7 is an example of a typical oestrogenic activation response from both the sediment and water samples of Nyamithi Pan, compared to the dose-response curve of the control 17β-oestradiol. The Phongolo River showed oestrogen activity during both sampling events. The concentration of oestrogen-active compounds was three orders of magnitude greater during the high-flow season (April 2013) than during the low-flow season (November 2012) (Table 6.7). However, the Nyamithi Pan showed an opposite trend: no quantifiable oestrogen activity could be detected for the samples from the high-flow season, while there were quantifiable levels in November 2012 (Table 6.7).

Aryl hydrocarbon receptor (AhR) activity

For the first sampling event (Table 6.8) the acid-washed (AW; containing persistent AhR ligands) and non-acid-washed (NAW; containing all AhR ligands) extracts for Nyamithi Pan and the NAW extract from the Phongolo River gave responses high enough to detect and quantify, while all of the extracts for the second sampling event (Table 6.8) gave a response high enough to detect and quantify, indicating that they, as well as those from the first sampling event, contain AhR ligands.

6.3.3 OCP levels

Only lipid weight values for the four species sampled are shown in Tables 6.9 and 6.10, because no significant differences were found between total lipid concentrations within the respective fish species. The characteristic lipophilic nature of OCPs also means that their accumulation is most relevant when the lipid weight readings are employed for analysis. The means and standard errors listed in Tables 6.9 and 6.10 show that ∑DDT is by far the highest concentration of OCPs accumulated within the lipids of the fish species studied, with its metabolite p,p'-DDE being the highest constituent of the overall levels of the OCPs determined. From these values it is noted that predominantly historical spraying of DDT is present within the study areas. Only two areas show values that are quite low, e.g. in the Nomaneni Pan in *H. vittatus* sampled during the high-flow April 2013 period and in *S. zambezensis* within the Phongolo River, also during the same sampling period. *Clarias gariepinus* and O. *mossambicus* showed similar trends at these localities.

Table 6.7. Results for the oestrogen activity assay for water and sediment sampled in November 2012 and April 2013.

November 2012												
	Phongolo River (stream)		Phongolo River (pan)		Nyamithi Pan		Nyamithi Pan (bridge)		Usutu River		Usutu River	
	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment
	pg BEQ/L	ng BEQ/g					pg BEQ/L	ng BEQ/g				
REP20	*5.30E+01	*1.12E+03	NA	NA	NA	NA	*5.83E+01	*2.23E+03	NA	NA	NA	NA
REP50	1.00E+00	4.63E-01	NA	NA	NA	NA	2.41E+00	5.99E+01	NA	NA	NA	NA
REP80	1.90E-02	1.90E-04	NA	NA	NA	NA	9.96E-02	1.61E+00	NA	NA	NA	NA
Apr 2013												
	ng BEQ/L	µg BEQ/g		µg BEQ/g		µg BEQ/g						
REP20	*1.13E+02	*3.92E+03	ND	*1.14E+05	0	*4.66E+04	ND	0	0	0	ND	0
REP50	5.69E+00	1.29E+01	ND	*3.18E+03	0	*1.89E+03	ND	0	0	0	ND	0
REP80	2.86E-01	4.25E-02	ND	8.86E+01	0	7.63E+01	ND	0	0	0	ND	0

*empirical data; NA = not sampled; ND = below limit of detection

Table 6.8. Results for the AhR activity assay for samples collected in November 2012 and April 2013 presenting the non-acid-washed extracts (all ligands) and the acid-washed extracts (persistent ligands).

November 2012												
	Phongolo River (stream)		Phongolo River (Pan)		Nyamithi Pan		Nyamithi Pan (Bridge)		Usutu River		Usutu River	
pg BEQ /g	All ligands	Persistent ligands	All ligands	Persistent ligands	All ligands	Persistent ligands	All ligands	Persistent ligands	All ligands	Persistent ligands	All ligands	Persistent ligands
REP20	*1.55E+01	ND	NA	NA	NA	NA	*8.83E+00	*8.98E+00	NA	NA	NA	NA
REP50	7.00E-02	ND	NA	NA	NA	NA	1.85E-02	9.00-02	NA	NA	NA	NA
REP80	1.00E-03	ND	NA	NA	NA	NA	4.63E-05	2.00E-03	NA	NA	NA	NA
April 2013												
REP20	*2.96E+01	*1.47E+01	*8.48E+00	*1.73E+01	ND	ND	*9.27E+00	*1.08E+01	*3.18E+01	*1.75E+01	*2.59E+01	*7.53E+00
REP50	1.77E+00	1.33E-01	2.99E-03	9.46E-02	ND	ND	7.43E-02	1.50E-01	1.33E+01	3.26E+00	2.41E-01	5.12E-02
REP80	1.31E-01	1.68E-03	1.77E-06	1.14E-03	ND	ND	6.39E-04	3.55E-03	6.68E+00	6.67E-01	6.27E-03	4.32E-04

*empirical data; NA = not sampled; ND = below limit of detection

Table 6.9. Organochlorine pesticide (OCP) levels in the muscle tissue of *O. mossambicus* and *C. gariepinus* sampled at the selected sites during the different surveys.

Lipid weight readings											
Species	***Oreochromis mossambicus***						***Clarias gariepinus***				
Survey date	November 2012	April 2013			September 2013		November 2012		April 2013		September 2013
Site	Nyamithi Pan	Phongolo River	Nyamithi Pan	Usutu River	Phongolo River	Nyamithi Pan	Phongolo River	Nyamithi Pan	Phongolo River	Nyamithi Pan	Nyamithi Pan
α-HCH	A 0.45 ± 0.29	BC 4 ± 2.67	BD 0.24 ± 0.24	ND	C 25.6 ± 9.79	AD 31.1 ± 10.6	ND	ND	ND	ND	ND
β-HCH	ND	A 10.5 ± 4.48	39 ± 21.1	A 0.89 ± 0.81	10.8 ± 3.74	25.2 ± 11.6	0.32 ± 0.31	ND	ND	ND	ND
γ-HCH	0.92 ± 0.48	ND	19.41 ± 13.6	36.79 ± 33	20.3 ± 3.99	26.12 ± 18	ND	0.1 ± 0.09	150 ± 49.9	46.1 ± 29.6	ND
δ-HCH	0.09 ± 0.08	5.27 ± 2.59	11.1 ± 8.67	62.7 ± 53.8	13 ± 4.21	24.3 ± 12.8	ND	ND	ND	ND	ND
∑HCH	A 1.46 ± 0.69	19.8 ± 7.56	70.79 ± 35	100 ± 87.4	69.6 ± 20.2	A 107 ± 51.1	0.32 ± 0.31	0.1 ± 0.09	150 ± 49.9	46.11 ± 29.6	
t-Chlordane	ND	4.44 ± 2.92	A 22.5 ± 15.48	3.26 ± 2.22	4.5 ± 2.51	A 3.85 ± 3.84	ND	ND	ND	0.19 ± 0.18	ND
t-Nonane	A 0.83 ± 0.83	6.29 ± 2.84	B 14.3 ± 13	5.65 ± 2.57	92.8 ± 44.6	AB 27.7 ± 15.7	ND	ND	9.57 ± 8.62	ND	ND
∑ CHLs	0.83 ± 0.83	10.7 ± 5.76	36.8 ± 28.5	8.91 ± 4.79	97,3 ± 47,1	31.6 ± 19.5			9.57 ± 8.62	0.19 ± 0.18	
p,p'-DDE	A 1.27 ± 0.42	73.2 ± 15.3	A 129 ± 55.11	220 ± 98.8	155 ± 60.4	A 105.7 ± 37	4.35 ± 0.49	a 4.16 ± 1.10	b 185 ± 56.8	bc 30.9 ± 18.8	ac 301 ± 124
o,p'-DDD	ND	5.66 ± 3.60	ND	2.08 ± 1.65	8.71 ± 4.4	4.1 ± 1.77	ND	ND	ND	ND	ND
p,p'-DDD	AB 0.1 ± 0.08	45.8 ± 25.05	A 83.3 ± 37.9	81.74 ± 39.78	99.1 ± 34.1	B 69.4 ± 20.7	ND	ab 0.23 ± 0.14	c 68.04 ± 15.45	acd 34.27 ±19.43	bd 161 ± 69.9
o,p'-DDT	ND	7.03 ± 4.16	AB 50.9 ± 50.6	A 19.9 ± 12.9	7.47 ± 3.4	B 8.16 ± 3.33	ND	ND	33.7 ± 7.83	5.45 ± 3.05	ND
p,p'-DDT	AB 0.17 ± 0.05	32.29 ± 20.3	A 42.1 ± 15.5	87.4 ± 44.28	72.4 ± 25.4	B 36.3 ± 10.3	ND	a 0.11 ± 0.08	32.9 ± 7.09	b 10.6 ± 4.57	ab 163 ± 72.5
∑DDT	1.55 ± 0.40	164 ± 50.7	A 305 ± 156	412 ± 195	343 ± 124	A 224 ± 68.3	a 4.35 ± 0.49	b 4.51 ± 1.15	ac 319 ± 76.2	bcd 1.2 ± 30.1	d 626 ± 266
HCB	ND	ND	ND	10.34 ± 6.82	0.75 ± 0.68	ND	ND	ND	ND	ND	ND
∑OCPs	3.84 ± 1.03	194 ± 55.3	413 ± 215	531 ± 278	510.7 ± 192	362 ± 125	4.68 ± 0.53	4.6 ± 1.12	479 ± 89.1	128 ± 55.6	626 ± 266

ND = below detection limits

∑Values with different superscripts show significant differences (Tukey's post-hoc test applied; p>0.05) *O. mossambicus* (A, B, C, D), *C. gariepinus* (a, b, c, d)

Table 6.10. Organochlorine pesticide (OCP) levels (mean ± SE) in ng/g lipid weight in the muscle tissue of *Hydrocynus vittatus* and *Synodontis zambezensis* sampled at the selected sites during the different surveys.

Lipid weight readings									
Species	***Hydrocynus vittatus***					***Synodontis zambezensis***			
Survey date	November 2012	April 2013			September 2013	November 2012	April 2013		September 2013
Site	Nyamithi Pan	Phongolo River	Nyamithi Pan	Nomaneni Pan	Nyamithi Pan	Nyamithi Pan	Phongolo River	Nyamithi Pan	Nyamithi Pan
α-HCH	ND	14.75 ± 8.58	ND	0.49 ± 0.22	122.48 ± 113.27	2.91 ± 2.13	1.23 ± 0.22	12.09 ± 7.16	6.71 ± 2.63
β-HCH	ND	0.05 ± 0.04	5.76 ± 3.72	0.10 ± 0.07	ND	ND	ND	ND	0.38 ± 0.13
γ-HCH	2.51 ± 2.50	5.21 ± 2.04	2.57 ± 1.35	0.50 ± 0.44	2.72 ± 2.72	7.36 ± 4.02	1.26 ± 0.51	1.81 ± 1.89	2.09 ± 0.62
∑HCHs	^{B}2.51 ± 2.50	^{A}20.01 ± 10.66	^{AB}8.33 ± 5.07	^{AB}1.09 ± 0.73	^{AB}125.48 ± 115.99	^{b}10.27 ± 6.15	^{ab}2.49 ± 0.73	^{a}13.90 ± 9.05	^{a}9.18 ± 3.38
trans-Chlordane	1.80 ± 1.79	ND	2.52 ± 1.34	ND	6.95 ± 6.77	0.58 ± 0.44	ND	ND	ND
trans-Nonachlor	ND	1.25 ± 0.23	1.53 ± 1.53	0.88 ± 0.34	2.41 ± 1.99	ND	4.47 ± 1.10	2.88 ± 2.30	4.10 ± 0.75
∑CHLs	^{B}1.80 ± 1.79	^{A}1.25 ± 0.23	^{AB}4.05 ± 2.87	^{AB}0.88 ± 0.34	^{AB}9.36 ± 8.76	^{b}0.58 ± 0.44	^{a}4.47 ± 1.10	^{b}2.88 ± 2.30	^{a}4.10 ± 0.75
p,p'-DDE	172.09 ± 53.41	67.81 ± 9.66	295.36 ± 42.83	38.51 ± 19.26	410.79 ± 158.83	189.01 ± 57.21	53.22 ± 13.51	28.01 ± 6.21	27.59 ± 5.73
p,p'-DDD	36.30 ± 15.58	10.23 ± 1.21	45.63 ± 9.40	16.97 ± 9.54	131.55 ± 40.90	51.12 ± 27.50	27.88 ± 6.60	7.71 ± 1.52	11.27 ± 2.17
o,p'-DDT	3.62 ± 3.61	4.32 ± 0.64	11.95 ± 5.42	4.34 ± 2.25	311.67 ± 247.03	9.61 ± 7.11	8.39 ± 2.31	3.10 ± 0.76	6.24 ± 1.08
p,p'-DDT	47.19 ± 17.02	17.63 ± 2.68	67.12 ± 20.99	20.66 ± 11.75	112.76 ± 39.46	63.19 ± 38.97	42.82 ± 12.22	11.13 ± 3.33	12.53 ± 2.25
∑DDT	^{AB}259.20 ± 89.62	^{B}99.99 ± 14.19	^{A}420.06 ± 78.64	^{A}80.48 ± 42.80	^{B}966.77 ± 486.22	^{a}312.93 ± 130.79	^{a}132.31 ± 34.64	^{a}49.95 ± 11.82	^{a}57.63 ± 11.23
HCB	ND	^{A}4.37 ± 4.01	ND	^{A}4.15 ± 1.83	ND	ND	^{a}0.20 ± 0.08	^{a}1.42 ± 1.08	^{a}2.08 ± 0.68
∑OCPs	263.51 ± 93.91	125.62 ± 29.09	432.44 ± 86.58	86.60 ± 45.70	1101.61 ± 610.97	323.78 ± 137.38	139.47 ± 36.55	68.15 ± 24.25	72.99 ± 16.04

ND = below detection limits

∑Values with different superscripts show significant differences (Tukey's post-hoc test applied; p>0.05) *Hydrocynus vittatus* (A, B or AB), *Synodontis zambezensis* (a, b or ab)

6.3.4 Biomarkers of exposure

Acetylcholinesterase (AChE)

There were no significant differences in AChE activity observed yet general trends indicated higher activity in the Phongolo River over time for both *O. mossambicus* and *C. gariepinus*. AChE activity decreased in April in *O. mossambicus* and in September in *C. gariepinus*. Temporal changes in AChE values were observed in *H. vittatus* and *S. zambezensis* within the Nyamithi Pan from the three sampling periods.

Metallothionein (MT)

MT results in *O. mossambicus* reflected consistently lower concentrations in The Phongolo River across the duration of surveys. There was an initial increase in MT concentrations in April followed by a decrease in September. Observations for *C. gari*epinus showed opposing trends as MT concentrations generally decreased in April and increased in September. Spatial differences are seen between the MT values in the tigerfish from the Phongolo River and the Nomaneni Pan during the April 2013 sampling period only.

Cytochrome P450 (Cyt P450)

A significant ($p<0.05$) increase in Cyt P450 activity was observed from November 2012 to April 2013. The Nyamithi Pan levels were noticeably higher in *O. mossambicus* while this trend was only reflected in *C. gariepinus* during the November 2012 survey. Spatial differences were present in the Cyt P450 levels in *H. vittatus* between the Phongolo River and the Nyamithi Pan within the Ndumo Game Reserve and the Nomaneni Pan which is located outside the reserve.

6.3.5 Biomarkers of effect

Protein carbonyl (PC)

PC activity generally demonstrated similar trends for both sites on the Nyamithi Pan reflecting significantly ($p<0.05$) higher activity in April 2013 and lower activity in September 2013 for both species. The PC results for *H. vittatus* from Nyamithi Pan differed significantly from the values of individuals sampled in the Phongolo River and Nomaneni Pan.

Lipid peroxidation (MDA) assay

Malondialdehyde (MDA) assay results showed significantly ($p<0.05$) high concentrations at the Phongolo River and Nyamithi Pan in September 2013 and low concentrations in April for both species. Trend results differed slightly in the Phongolo River in November 2012 where MDA levels were noticeably lower and later increased towards April 2013. Significant temporal changes were found in the MDA levels in *H vittatus* and *S. zambezensis* in the Nyamithi Pan during the different surveys.

Superoxide dismutase (SOD)

Superoxide dismutase (SOD) results for *O. mossambicus* showed significant differences ($p<0.05$) mainly between the Phongolo River and Nyamithi Pan in November and September while in *C. gariepinus* significant differences were only seen in the Phongolo River between November 2012 and April 2013. Generally, SOD activity was the highest in April 2013.

Catalase (CAT)

Catalase (CAT) activity in *O. mossambicus* reflected significantly ($p<0.05$) high activity in April for both the Phongolo River and Nyamithi Pan with the lowest activity being evident in November 2012 for the Phongolo River and in September 2013 for Nyamithi Pan for both species. Catalase reactions between the Phongolo River in April 2013 and the Nyamithi Pan in September 2013 showed significant differences. Significant differences in CAT values were also observed in *S. zambezensis* showing temporal changes in the Phongolo River and Nyamithi Pan.

Reduced glutathione (GSH)

Reduced glutathione (GSH) activity exhibited similar trends to MT results for both species with the activity being significantly ($p<0.05$) high in April 2013 and low in November 2012. For the Nyamithi Pan the highest activity was observed in September 2013 while the lowest was observed in April 2013 for *O. mossambicus* and in November 2012 for *C. gariepinus*.

Cellular energy allocation (CEA)

Results show a significant progression in CEA activity ($p<0.05$) in both species from November 2012 through to April and September 2013. Results observed for *O. mossambicus* in the Usutu River showed a divergence from other results as the CEA activity was observed to be at its lowest in April 2013. No observable changes were found in the CEA values in *H. vittatus* sampled from the different sites. *Synodontis zambezensis*, however, showed temporal changes during the sampling periods.

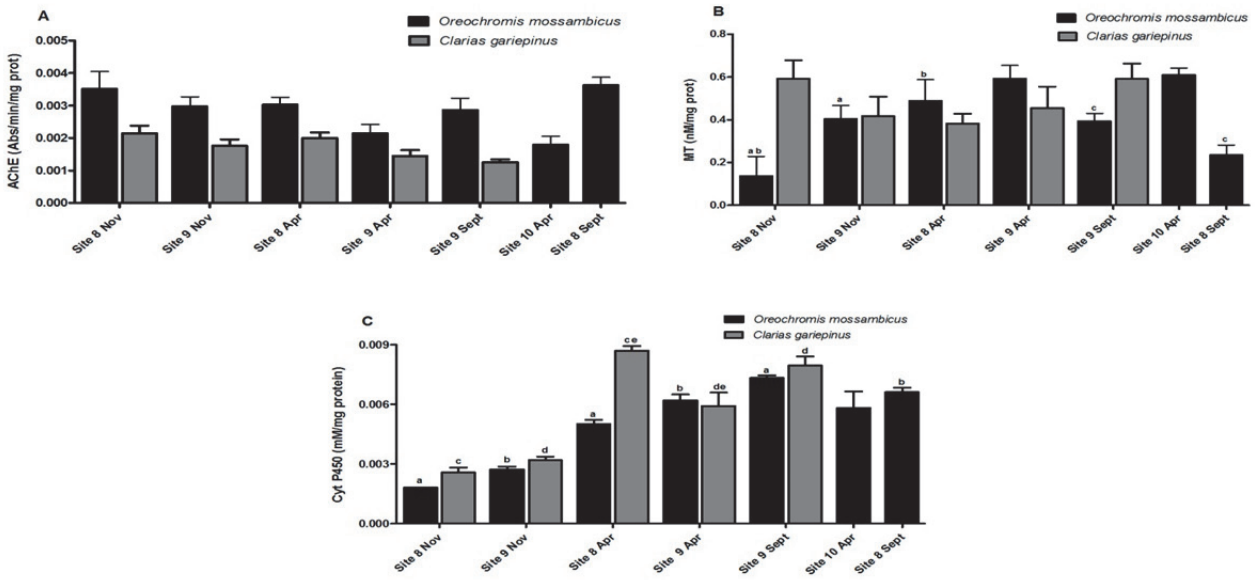


Figure 6.2. Graphical representation of biomarker results showing biomarkers of exposure (A-C) for *O. mossambicus* and *C. gariepinus* in the Phongolo River, Nyamithi Pan and Usutu River from November 2012 to September 2013. Common superscripts indicate significant differences ($p<0.05$) between sites while error bars represent standard error of the mean (±SE) for both species.

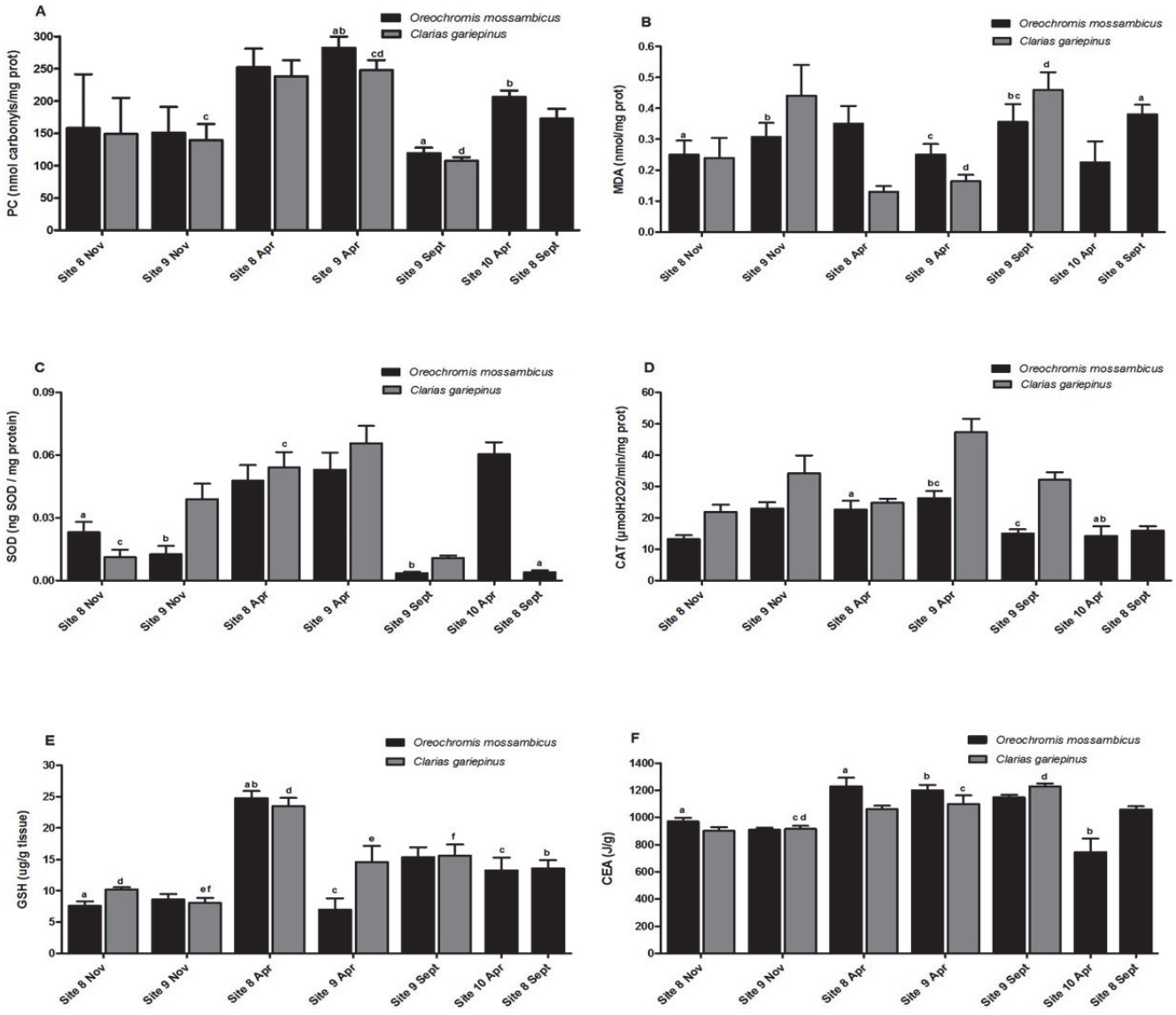


Figure 6.3. Graphical representation of biomarker results showing biomarkers of effect (A-F) for *O. mossambicus* and *C. gariepinus* in the Phongolo River, Nyamithi Pan and Usutu River from November 2012 to September 2013. Common superscripts indicate significant differences ($p<0.05$) between sites while error bars represent standard error of the mean (mean ± SE).

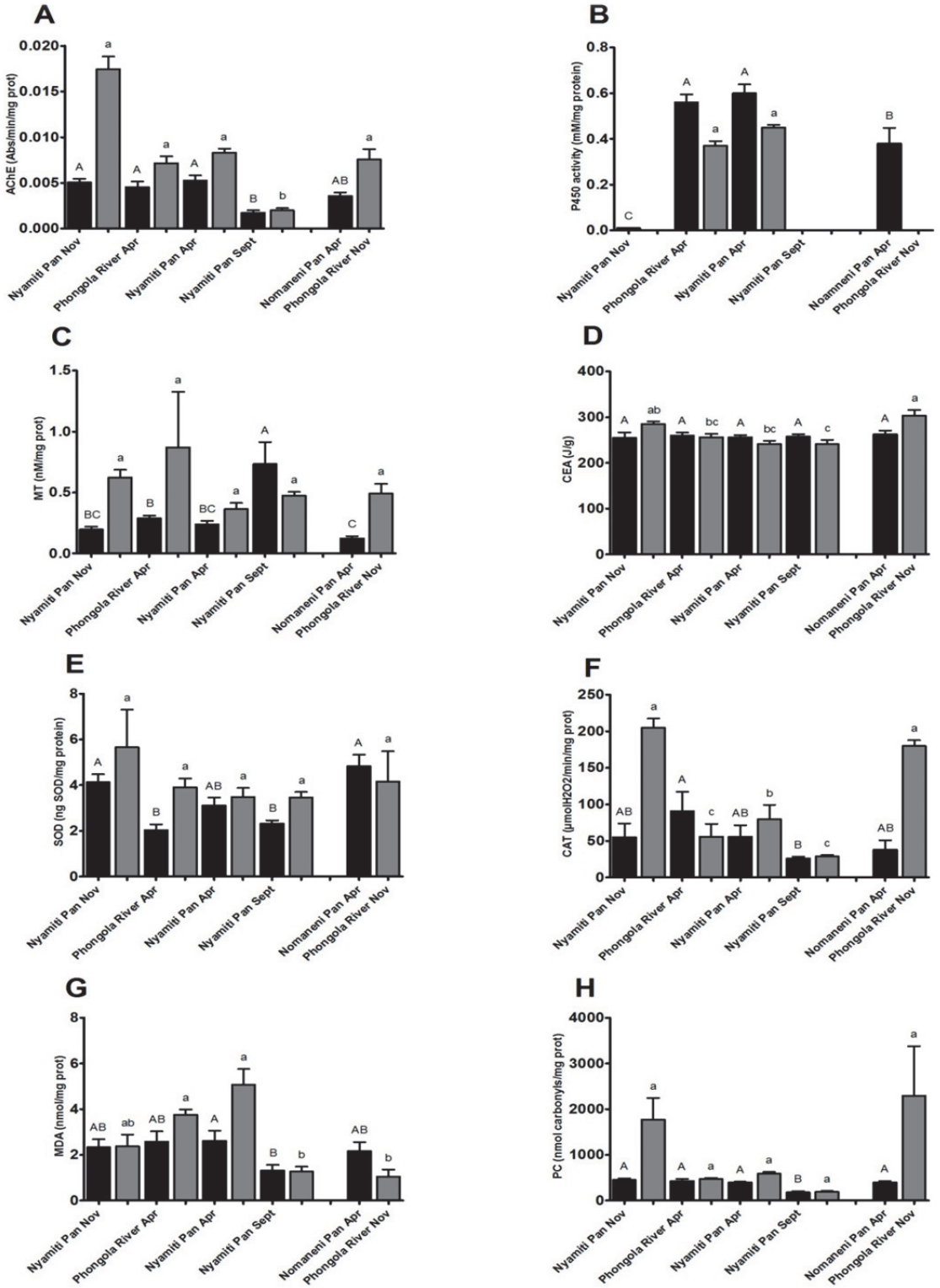


Figure 6.4. Graphical representation of biomarker results showing biomarkers of exposure (A-C) and biomarkers of effect (D-H) during the different sampling surveys. Solid black bars represent *H. vittatus* and grey bars with black outlines show *S. zambezensis*. Significant differences ($p<0.05$) are shown in capital letters (A, B, AB, C) for *H. vittatus* and in lower-case letters (a, b, ab, c) for *S. zambezensis.*

6.4 Discussion

The results of organic compound accumulation analyses in the fish tissue indicate that the main compounds observed were lindane, chlordane and DDT. Because of the high levels of DDT found accumulated in the selected fish species sampled, it is possible that if dramatic biomarker responses were observed, it was due to the spaying of DDT for malaria vector control. Determination of metal accumulation in fish tissue did not form part of this study, but are included in the discussion to interpret changes in metallothionein levels.

Bioassays provide reliable and effective measurements of the potency of a substance and the possible effects or stressors affecting a specific ecological system. Spatial differences in biomarker readings vary within organisms based on the environmental factors they are exposed to within different regions, but temporal differences are those which are seen within the same system at different times. For this reason it is important to consider the physical parameters of specific systems when assessing biomarker responses. Responses may take the form of up- or down-regulation (excitation or inhibition), of specific compounds which aid in the detoxification process.

The discussion mainly focuses on the trends observed at the different sites during the surveys for *O. mossambicus*, *C. gariepinus, H. vittatus* and *S. zambezensis*. These trends were evaluated for the survey periods, e.g. controlled flooding (November 2012), high (April 2013) and low (September 2013) seasonal flows. The diagnostic nature of biomarker responses (Table 6.11) was used to interpret and discuss the findings on the possible toxic effects of OCPs sprayed in the study area during the relevant survey periods (Wepener et al., 2005).

6.4.1 Cell-line reaction

The cell culture results suggest that the sites surveyed on the Nyamithi Pan are the most affected by pollution. This is because the pollutants occurring in this pan are of the more persistent nature, meaning that they resist natural breakdown processes, causing their prolonged presence in the pan. This is clearly seen in the sampling events of November 2012 as well as in April 2013. Both pans adjacent to the Phongolo River have lower responses compared to that of the Phongolo River, suggesting that Site 8 is more polluted. Thus the pollution may be waterborne, possibly because of water being polluted by activities such as tourism (boats in the water), and not due to atmospheric transport. However, it should be noted that the sites along the Phongolo River were observed to have pollutants of the more persistent nature.

6.4.2 Biomarkers of exposure

Acetylcholinesterase (AChE)

While the majority of the biomarkers within this study show changes when up-regulation occurs, AChE is the opposite in that down-regulation is what is considered to be important. The reading observed in the Nyamithi Pan during the September 2013 sampling period was found to be the lowest and most significantly different from almost all of the other sites. This reading corresponds with the highest ∑DDT concentrations found within *H. vittatus* and *C. gariepinus*. This finding is important because exposure to cholinesterase-inhibiting pesticides prevents the breakdown of acetylcholine and is one of the reasons why the up-regulation of this enzyme is inhibited. Up-regulation of this enzyme is needed for the transfer of nerve impulses that control specific body functions (Wepener et al., 2005).

Metallothionein (MT)

Metallothioneins are proteins that have the capacity to bind essential physiological (Zn, Cu, Se) and xenobiotic (Cd, Hg, Ag, As) metals (Viarengo et al., 2007; Alvarado et al., 2005). Once MT is bound it is rendered inactive and excreted from the body. Metal levels were not determined in fish tissues, the water or the sediment during this study. However, this does not mean that they were not at all present within the systems sampled. Metal accumulation within an organism is a result of the total bioavailability of the metals within a system. If these metals are not bioavailable, it generally means that they have become part of the sediment because the sediment within a system is generally considered to be a reservoir of metals. Aquatic organisms therefore may acquire metals from either the water or the sediment. The high levels of MT in *H. vittatus* found in the Nyamithi Pan during September 2013 correspond with the highest reading of ∑OCPs, but since MT is triggered by the presence of metals we can conclude that metals are present within all the sites, but that there was a particularly high metal concentration during this period and at this particular site. Mechanisms used to control bioaccumulation of metals within *H. vittatus* have been studied and they show that often higher levels of metallothioneins are induced when fish are exposed to higher levels of metals in the direct environment (Tom et al., 2004). It is reasonable to assume that metals are present within the sites as most MT genes respond with up-regulation after exposure to metals, as shown by the MT results (Fisher, 2011; Tate, 2013). The generally higher MT reading in the Nyamithi Pan compared to that in the Phongolo River supports this assumption (Tate, 2013).

Cytochrome P450 (Cyt P450)

Cytochrome P450 was not detected in any of the sites sampled during this study. This biomarker indicates possible exposure to toxicants and these toxicants are derived from a wide variety of sources and can have various compositions. Specific toxicants are not required for the activation of cytochrome P450 1A (CYP1A). The most significant increases in CYP1A levels were observed in the Phongolo River and the Nyamithi Pan in April 2013, but the accumulation levels in fish from the Phongolo River during this period do not correspond with the highest overall levels of ∑OCPs. The detoxification activities in the liver of the fish analysed were observed not to be very high, which probably indicates that the toxic levels of the OCPs were below physiological risk levels.

Table 6.11. The diagnostic nature of the biomarker responses and their interpretation (Wepener et al. (2005).

Biomarker	Increase/decrease	Exposure or effect interpretation
Acetylcholinesterase (AChE)	↓	Inhibition due to pesticide exposure
Metallothionein (MT)	↑	Stimulation in the presence of metals
Cytochrome P450 (CYP1A)	↑	Stimulation in the presence of organics
Catalase (CAT)	↑	Produced in response to ROS formation
Superoxide dismutase (SOD)	↑	Produced in response to ROS formation
Malondialdehyde (MDA)	↑	Indicative of lipid peroxidation due to ROS
Protein carbonyl (PC)	↑	Damage to proteins due to ROS
Cellular energy allocation (CEA)	↓ and ↑	Decrease due to stress compensation requiring additional energy sources. Increases associated with additional energy sources.

6.4.3 Biomarkers of effect

Protein carbonyl (PC)

The increased presence of reactive oxygen species (ROS) can lead to increased protein oxidation resulting in protein carbonyl formation as a means of detoxification (Parvez & Castegna et al., 2003). An elevation in PC levels can indicate an elevation of normal metabolic process requiring protein oxidation, pesticide (mainly deltamethrin, endosulfan and paraquat) presence, disease, injury or inflammation (Parvez & Raisuddin 2005; Dalle-Donne et al., 2006). Generally, a low PC concentration was observed within all sites and during all sampling periods, meaning that although there are stressors present, they seem to be having little to no effect on the protein structures within the organisms. The lowest significant difference is seen within the Nyamithi Pan, again during the September 2013 sampling period, which was significantly lower than at all other sites and sampling seasons.

Lipid peroxidation (MDA) assay

Lipid peroxidation results in the formation of malondialdehyde (MDA) which is an indicator of the effect of metals and trace organics (Dalle-Donne et al., 2006; Cazenave et al., 2009). Polyunsaturated acid peroxidation is the major cause of the formation of malondialdehyde within organisms (Flohr et al., 2011). The general trend observed of a higher concentration of MDA in fish from the Phongolo River suggested that MDA levels are increased at this site due to oxidative stress. These higher malondialdehyde levels during the low-flow season were probably the result of the presence of pesticides affecting the physiological condition of the fish (Solè et al., 2010; Parihar et al., 1996).

Superoxide dismutase (SOD)

Superoxide dismutase and catalase work hand in hand as the first line of defence in controlling oxidative stress and can be seen as the first step in the response to lipid peroxidation, whereby SOD converts the superoxide anion (O_2^-) to molecular oxygen (O_2) and hydrogen peroxide (H_2O_2) which is further converted to H_2O and O_2 by catalase (CAT) (Marklund & Marklund, 1974). The most notable change is the significantly higher reading in the Nyamithi Pan in November compared to the same site in September 2013. This fluctuation showed an increase in environmental stress that could include an increase in OCP levels in Nyamithi Pan. Tigerfish show a high accumulation of OCPs during this period. These changes and reaction to the toxicants seem to be sufficient to prevent serious physiological effects in the fish.

Catalase (CAT)

The corresponding trends in CAT and SOD responses confirmed that they act synergistically to neutralise free radicals in order to prevent tissue and cell damage in specifically *O. mossambicus and C. gariepinus* (Dorval & Hontela (2003); Pandey et al., 2003). The higher CAT activity observed in April 2013 and November 2012 is in reaction to the toxicant levels but is successfully regulated by the fish. The catalase changes in *H. vittatus* were neither spatial nor temporal in nature; this finding is not of great importance and does not indicate a change that can be considered relevant.

High flows can result in increases in pesticide presence caused by runoff which is known to amplify environmental stress in biota and in the case of fish increasing the presence of ROS and yielding corresponding CAT induction. Both SOD and CAT activity was noticeably lower during the lowest flow period of September 2013 with fish from Nyamithi Pan reflecting a lower reaction to the water quality.

Reduced glutathione (GSH)

Glutathione (GSH) is part of the phase II biotransformation enzymatic system. Glutathione is known for its antioxidant ability as well as its affinity for metals. Induction of GSH is usually an indication of oxidative stress or the presence of endocrine-disrupting chemicals (Kovačević et al., 2008). Phase II detoxification occurs by a process of conjugation where the GST (glutathione S-transferase) enzyme catalyses the conjugation of GSH with a xenobiotic compound in order for toxicant excretion to ensue (Van der Oost, 2003). Glutathione has a high affinity for electrophilic compounds and levels have been known to elevate in the presence of PCBs (Pérez-López et al., 2002). The highest levels observed in April 2013 in the fish species could be in reaction to OCP level increases during higher rainfall periods and active pesticide spraying.

Cellular energy allocation (CEA)

Cellular energy allocation is a biomarker reflecting the effect of stressors on energy reserves and metabolism; it is expected that these reserves deplete during high stress conditions due to increased metabolism, cellular repair or detoxification (Gourley & Kennedy, 2009). The CEA levels were lower during November 2012 during a high-flow period after artificial flood releases.

It would be expected that energy reserves are much higher during this time due to an elevation in nutrient levels resulting from increased sediment re-suspension and surrounding soil erosion. On the other hand, the lower levels observed in November 2012 could be the result of increased stress on the organisms caused by increased water pressure where

some organisms that cannot cope are forced to find alternative reservoirs to escape the high flows. Increased spawning and migration activities during this period are also known to have an effect on energy reserves.

However, the CEA results for April 2013 corroborate the expectations mentioned before, since April was also a high-flow period during the natural rainfall season.

6.5 Conclusion

The combined effect of environmental conditions and the impacts related to pesticide presence are currently affecting the health of the fish species used for the assessment of biomarker responses. DDT had the highest accumulation levels in all species at all the sampling sites. The toxicant levels tended to be elevated over the highest flow periods, mainly in the Phongolo River. The elevated toxicant levels tended to persist in Nyamithi Pan during low-flow periods as a result of high evaporation rates and the lack of freshwater inflows. The flood release events affected CEA levels as more energy was expended to compensate for increased water pressures.

The fish species studied displayed individual and specific reactions in the biomarker responses; this finding demonstrates that changes in the toxicant levels during wet and dry seasons vary. The water volume and pesticide application are probably causing these fluctuations. The fish species have regulatory mechanisms to cope with the varying levels of contamination that prevent a permanent or long-term effect on the physiological functioning of the organisms. The health status of the fish studied is therefore not affected. The current fish populations in the area will remain stable and no change in diversity is expected.

Future monitoring of the biomarker responses is advised to be able to identify changes in the biomarker responses and OCP levels in the surface water of the system.

No cytotoxic responses were observed in any of the extracts examined in the H4IIE-luc cell bioassays and MTT cell viability assays, providing support that dead or dying cells alone did not induce luciferase activity in the H4IIE-luc cells. This finding corroborates the findings on biomarker responses.

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7 BIODIVERSITY: OBSERVED THREATS AND POTENTIAL CONSERVATION INTERVENTIONS FOR SELECTED INVERTEBRATE AND VERTEBRATE GROUPS

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7.1 Introduction

7.1.1 Freshwater ecosystem

The intricate interlinkages between biota and the physical environment form the framework for humanity's interaction and survival. Many of the poorest and most disadvantaged in this world are critically dependent for their sustenance and health on their immediate environments and ecology. Short-term exploitation, whether from necessity or personal gain, often depletes and degrades the sustaining environment beyond the capacity of that environment to maintain the functions for the future. Where such a tension occurs, it is imperative to measure the stresses so that the situation can be described and information for mitigation and conservation provided.

In a recent biodiversity assessment of freshwater ecosystems in South Africa (National Biodiversity Assessment 2011), the loss of biodiversity was regarded as a serious threat to ecosystem functioning (Nel & Driver, 2012). The ecosystem threat status of a freshwater ecosystem indicates the degree to which the ecosystem is still intact or alternatively losing vital aspects of its structure, function and composition, on which its ability to provide ecosystem services ultimately depends. The assessment reported that 55% of South Africa's river ecosystems are threatened and that wetlands are even worse off, with 65% of South Africa's wetland ecosystems being threatened, while 48% of wetlands are critically endangered (Nel & Driver, 2012).

The study area for the present study lies within the Lowveld Ecoregion (Level 1). In order to cover the unique diversity of amphibians in the area the study also included pans and streams within the catchment. In the assessment of South Africa's biodiversity and ecosystems (National Biodiversity Assessment 2011), the ecosystem threat status (ETS) and ecosystem protection level (EPL) for each river system were determined. Lowland river ecosystems in this ecoregion, such as the Lower Phongolo River, were categorized as

Critically Endangered and with an Intermediate Level of Protection (conservation). Rivers in the Lebombo Uplands Ecoregion were categorized as Least Threatened.

The study area is a low-lying and humid tropical floodplain in Maputaland. The Ndumo Game Reserve (NGR) in particular is known for its magnificent birdlife (Whittington et al. 2013). The reserve was established in 1924 to protect hippos after the area had been severely impacted by uncontrolled hunting. The Ndumo Game Reserve hosts a diverse range of habitats, including sand forest, dense riverine forest, floodplains, alluvial plains, reed beds, grassland, broad-leaved and acacia woodlands and extremely dense thornveld. The wetlands vary from small roadside pools, seasonal pans, vlei areas, streams to the large Banzi and Nyamithi Pans. This diversity in aquatic habitats caters for a variety of aquatic invertebrates, fish, amphibians and birds.

In a recent assessment of the status and distribution of freshwater biodiversity in Southern Africa, Darwall et al. (2008) reported that the major threats to freshwater biodiversity in South Africa include:

- Water abstraction, impoundment and interbasin transfers
- Invasive alien species
- Sedimentation and pollution

7.1.2 Macroinvertebrates

Information in the literature on macroinvertebrate diversity in the Lower Phongolo system, as well as its conservation importance, is severely limited as no detailed assessments have been conducted in recent years. Regional information is available on selected macroinvertebrate groups, such as freshwater crabs, dragon flies and damselflies and to a limited extent, on freshwater prawns. A literature search showed that aquatic macroinvertebrates have only been sampled as part of the River Health program at an impacted site on the Ngwavuma River. As such, an assessment of the diversity of macroinvertebrates and their conservation importance must be based on information at a more regional scale.

A total of 122 freshwater mollusc species is known from the southern African region. Of these, 99 species are gastropods belonging to 15 families and 23 species are bivalves belonging to six families (Darwall et al., 2008). Of these, 2% are Critically Endangered (CR), 6% are Endangered (EN), 3% are Near Threatened (NT), while 54% are of Least Concern (LC). A disturbing fact is that 39 species are categorized as Data Deficient (DD). Twenty

species of freshwater molluscs are known to occur in the study area (Bruton & Cooper, 1980).

7.1.3 Freshwater fishes

In total 44 fish species from 12 families have been reported from the Lower Phongolo River and floodplain. Of these species, two, the tigerfish *Hydrocynus vittatus,* and the black tilapia, *Oreochromis placidus* were included in the South African Threatened or Protected Species list (TOPS-list) of 2007 (DEAT, 2007). Recently (2013) the Mozambique tilapia, *Oreochromis mossambicus* was also included in the Protected Species category (DEAT, 2013). To date, one exotic species, the common carp (*Cyprinus carpio*) has been reported to occur in this region. The Lower Phongolo River and its associated floodplains are considered as one of the freshwater fish biodiversity hotspot areas in South Africa and host almost half of all known species from this region (Skelton, 2001). One of the biggest threats to the fishes of the study area is the alteration of the natural flow regimes in the system. This is not unique to the Phongolo River system as alterations to natural flow have been documented as one of humankind's biggest disturbances to the environment (Bain et al., 1988).

Hydrological alterations have been so extensive that most of the rivers in the northern third of the world are either moderately or strongly affected by damming, fragmentation, inter-basin diversion or irrigation (Dynesius & Nilsson, 1994). Numerous studies have been done during the past three decades to determine the effect of altering flows on fish communities and fish population (Bain et al., 1988; Merron et al., 1993; Freeman et al., 2001; Kobza et al., 2004; Naghibi & Lence, 2012). These studies have emphasised the importance of maintaining a minimum hydrological flow standard in order to ensure that aquatic organisms can survive droughts (Naghibi & Lence, 2012).

Following completion of the Pongolapoort Dam in 1973 and up until 1987 the Department of Water Affairs (DWA) managed the impoundment taking into consideration problems with the wall buttress. The latter resulted in that the DWA had to keep dam levels low so that they could accommodate a flood without damage to the wall. Operating the dam in this way damaged the outlet system and even when the wall had been fixed the dam was still operated at low levels while the outlets were fixed. For some year following the original completion date it was thus not possible to release floods. During the period 1986 to 2013 the timing of the artificial flood release from the Pongolapoort Dam was determined through a stakeholder consultation process taking into account the needs of the local communities, the agricultural community and the Department of Water Affairs. When comparing the peak inflow into the Pongolapoort Dam (natural flooding) with the peak outflows (artificial flooding) from 1986 to 2013, it is clear that to date the environmental needs have not been taken into

account when determining the artificial flood regime (Table 7.1). The 1986 to 2013 data showed that 69% of the natural flood occurs in summer (December to February) and 65% of the flood releases occur during spring (September to November), thus over the past 38 years very few of the artificial flood releases coincided with natural flood events (Table 7.1).

The aim of this section of the project was therefore to determine whether fish biodiversity and community structures of the Lower Phongolo River and the associated floodplain have been affected by the altered flood regime. This was done by comparing the data collected during the present study with data from 1974-1976, 1983, 1984, 1993-1994 (Merron et al., 1993; Merron et al., 1994a-f), specifically focusing on biodiversity and fish community structures.

Table 7.1. Comparison of the timing of the peak inflows into the Pongolapoort Dam (natural flooding) with the peak outflows (artificial flooding) from the dam of 38 flood events from 1986 to 2013.

Inflows		**Outflows**	
Month	**Percentage**	**Month**	**Percentage**
January	14%	January	0
February	21%	February	14%
March	17 %	March	7%
April	0	April	0
May	0	May	0
June	0	June	0
July	0	July	7%
August	0	August	3%
September	3%	September	10%
October	3%	October	41%
November	7%	November	14%
December	34%	December	3%

7.1.4 Frogs

Amphibians are very diverse and have adapted to a variety of habitats throughout the world. According to Frost (2014) there are globally more than 7 302 known amphibian species. In recent decades amphibians have suffered sudden, high mortality rates with many species becoming extinct. There are many different factors contributing to this decline in amphibian populations. The most significant cause is habitat loss and fragmentation through anthropogenic disturbances. According to Du Preez and Carruthers (2009), frogs inhabits almost every environment and habitat on the subcontinent. Even though frogs are found in a wide variety of environments, most species are very specific to the particular habitat in which they are able to survive and, more importantly, reproduce. Because of this specialisation

many frog species are vulnerable to changing habitats and are directly affected by such disturbances (Graeter et al*.,* 2008). In terms of amphibian species diversity, South Africa is currently ranked as the 27th country with the greatest known amphibian species richness at a global level (Measy, 2011).

Within South Africa, the greatest amphibian species diversity can be found in the eastern part of the country and in particular in the Province of KwaZulu-Natal (KZN) (Measey, 2011). According to Minter et al. (2004), KZN is one of the provinces with the greatest richness of endemic species in South Africa. Northern KwaZulu-Natal contains a rich diversity of frog species, mainly because of its habitat, biodiversity and its warm climate. The tropical conditions and moist savannah of KZN seem to be the preferred habitat for the diversity of frog species. This could be due to the tropical weather conditions, as well as relatively high rainfall and variety of rivers that arise on the escarpment and cross the coastal plain to the sea. As a result of the steep escarpment (towards the sea) numerous deeply incised river valleys helped form a complex landscape with diverse habitats. With such diverse and complex habitats, it is possible that a greater number of amphibian refuges were available, increasing the potential for speciation over time (Minter et al., 2004). KwaZulu-Natal is an important refuge for a number of endangered and endemic frog species; however, environmental stress due to anthropogenic activities is posing a serious threat to the survival of these species, and protected havens become more important for the survival of the amphibian species richness in KZN. Officially, the only protected portion of the Phongolo floodplain is the section consisting of the Phongolo River and associated pans in the Ndumo Game Reserve, an area recognised as a biodiversity hotspot for amphibians (Alexander et al., 2004). Currently there are 71 different species (excluding subspecies) in KZN; these account for 43.3% of the total diversity of frog species that occur in southern Africa (see Du Preez & Carruthers, 2009; Channing et al., 2013a; b; Conradie, 2014). According to the historical data provided by Ezemvelo Wildlife a total of 39 different species have been documented (between 1929 and 2001) in the NGR and surrounds.

7.1.5 Birds

There are more than 2 300 bird species on the African continent, providing and maintaining functions such as pollination, fruit and seed dispersal, scavenging, and predation of insects, fish, frogs and other small vertebrates. Birds also provide economic value, directly via tourism, and indirectly through capacity-building, environmental awareness, and national pride. All these elements contribute towards supporting the global sustainability agenda. More than 800 bird species occur in South Africa (37% of Africa, and 7% of the world's diversity). The NGR is located at the southern end of the coastal plain that originates in Somalia. This continental feature allows the north-south distribution of many Afrotropical

birds that would otherwise not have occurred in South Africa or the NGR. Twelve species of the 38 bird species characteristic to the eastern coastal plain of Africa have their southernmost distribution in the coastal sand forests of northern KwaZulu-Natal, making NGR a critical site for bird diversity in South Africa. The NGR is world-renowned as an ecotourism destination, with a particular focus on birders. It boasts a bird list of 430 species (19% of the species for the whole of Africa), the highest density of bird species in South Africa. Much of the diversity is also due to the riverine habitats that are available. Birds, with their ability to locate to sites more suitable, provide an excellent suite of indicators of the state of the environment measured.

7.1.6 Aims related to assessing the biodiversity of the Phongolo River and floodplain

The specific aims of this part of the study were to:

1. Establish the current status of selected aquatic macroinvertebrate, fish, amphibian and aquatic bird communities of the Lower Phongolo River.
2. Identify and characterise threats to the aquatic macroinvertebrate, fish, amphibian, and aquatic bird communities.
3. Propose priority management and conservation interventions to halt and reverse potential threats.

This information can then inform the biodiversity action plans for the protection of a unique centre of biodiversity in South Africa.

7.2 Materials, methods and sites

7.2.1 Macroinvertebrates

Macroinvertebrates were collected using standard operating procedures as explained in Chapter 4, Section 4.2.2. A list of macroinvertebrates that were collected in aquatic habitats during the course of the study is provided (Table 7.4); however, the focus of discussions will be on threatened and invasive species.

7.2.2 Fish

See details on methodology pertaining to fish as stipulated in Chapter 2, Section 2.5.1.

7.2.3 Amphibians

In order to cover the breeding season for all frog species in the area, surveys were conducted so as to cover all the seasons. Surveys were undertaken during the periods 9-19 April 2013, 30 July to 3 August 2013, 10-14 September 2013, 17-21 November 2013 and 3-7 February 2014. Sites were selected to cover the variety of wetlands in the catchment and also to cover the protected area as well as the communal area.

A variety of methods were used to capture data. These included acoustic surveys, pit traps, visual-encounter surveys (VIS) and ad hoc collection of samples. An acoustic survey was conducted at each site at night. For a period of 5 min the call notes of all frog species were noted, and a score out of five was assigned for abundance and a score out of five for call intensity. Additional acoustic data were obtained by means of a programmable song meter (Figure 7.1) that was set up at Site 13 to record frog calls for 10 min out of every nocturnal hour (18:00 to 06:00) from April 2013 to August 2014 and from August 2014 until October 2014 onwards at Site 13. This song meter was used to collect seasonal data, as well as breeding activity of different amphibian species across a period of 18 months.



Figure 7.1. Solar-powered song meter installed in a protective housing and attached to a tree.

During the daytime, frogs were spotted by walking through each site. Frogs were collected by hand and placed individually in a plastic bag. For parasite screening, bags containing frogs were transported back to the laboratory in a Coleman cooler box. Frogs were housed individually in water overnight.

Parasite diversity and parasite load may provide valuable insight into the general condition of frogs. For this reason we screened for polystomatid flatworm parasites and for haemoparasites. After a period of at least 12 hours the specimen was removed and the water screened for the presence of flatworm eggs. The water was poured through a pair of plankton sieves with respective mesh sizes of 500 µm and 100 µm. The 500 µm sieve retains all the course debris while flatworm eggs and fine debris collect on the second sieve. The contents of the 100 µm sieve was washed into a small Petri dish and carefully screened for parasite eggs using a dissecting microscope.

A drop of blood was obtained from the *arteria femoralis* using a 1 mL insulin needle. Two thin blood smears were prepared for each specimen dissected. Air-dried blood smears were fixed in methanol for 4 min and allowed to dry until further processing.

Since amphibians utilize a wide variety of habitats and since the smaller seasonal pans are such important habitats catering for anuran diversity, additional sites were identified and sampled (Figure 7.2). Over and above the sites covered in Chapter 2, additional sites were identified (Tables 7.2 and 7.3).

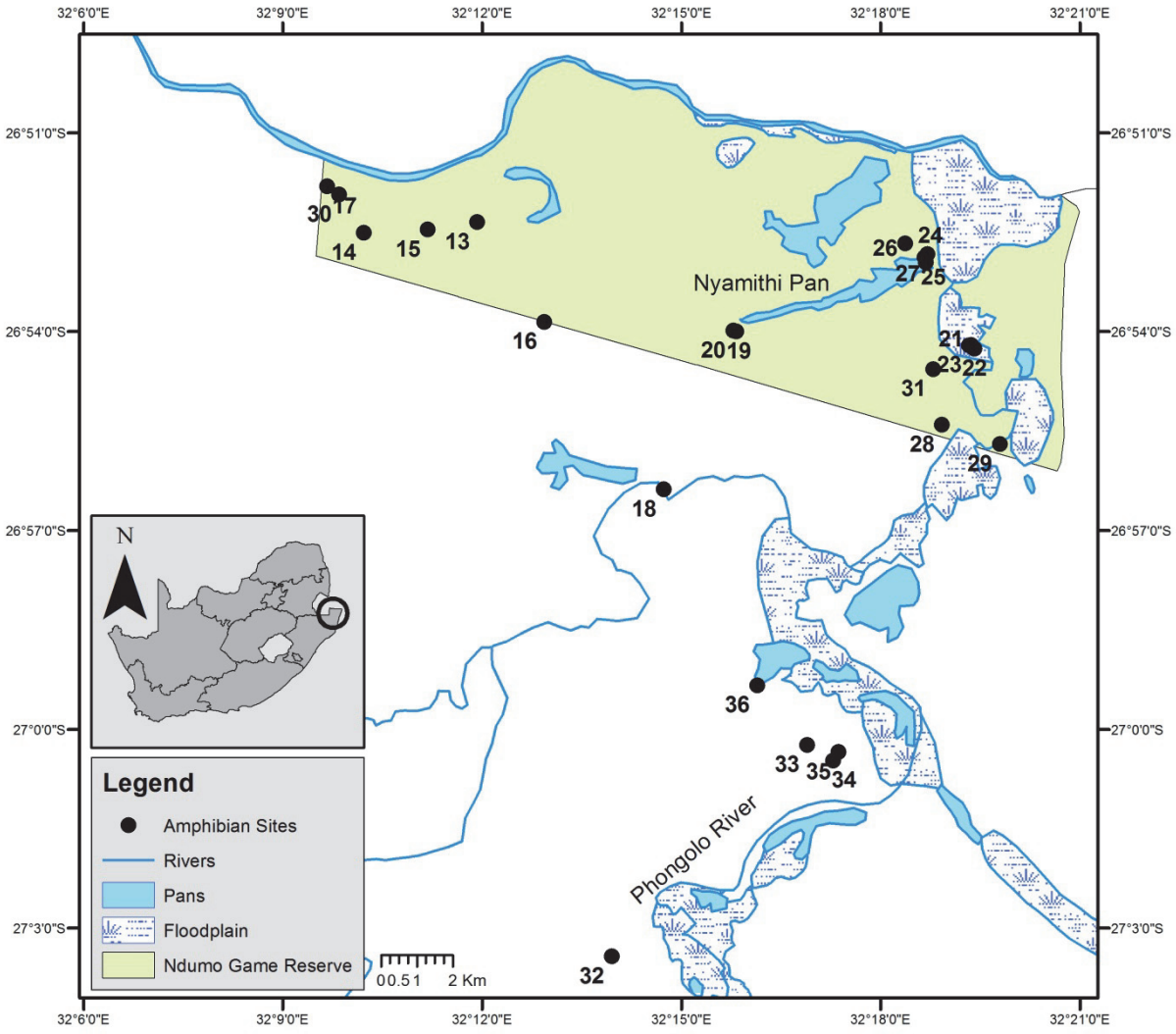


Figure 7.2. Additional localities where frogs were collected.

Table 7.2. Specific sampling sites for amphibian survey inside Ndumo Game Reserve.

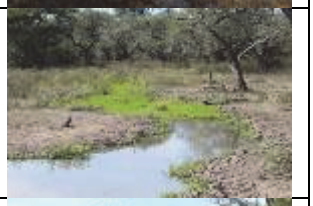
Site number	13	
GPS coordinates	26.87249 S 32.19878 E	
Description	Bumbanini Pan	
Site number	14	
GPS coordinates	26.87518 S 32.17032 E	
Description	Phaphukhulu natural spring	
Site number	15	
GPS coordinates	26.87433 S 32.18638 E	
Description	Matendeni Pan	
Site number	16	
GPS coordinates	26.89756 S 32.21565 E	
Description	Ziposheni Pan	
Site number	17	
GPS coordinates	26.86347 S 32.16112 E	
Description	Fontane Pan	
Site number	18	
GPS coordinates	26.56276 S 32.14330 E	
Description	Lowveld riverine forest	
Site number	19	
GPS coordinates	26.90001 S 32.26378 E	
Description	Vlei area	
Site number	20	
GPS coordinates	26.89980 S 32.26304 E	
Description	Pool	

Table 7.2. (continued).

Site number GPS coordinates Description	21 26.90337 S 32.32266 E Pan	
Site number GPS coordinates Description	22 26.90434 S 32.32353 E Densely covered terrestrial site	
Site number GPS coordinates Description	23 26.90344 S 32.32219 E Stream feeding into pan	
Site number GPS coordinates Description	24 26.88265 S 32.31132 E Riverbank	
Site number GPS coordinates Description	25 26.88135 S 32.31106 E Vlei area with small stream	
Site number GPS coordinates Description	26 26.87782 S 32.30613 E Pan	
Site number GPS coordinates Description	27 26.88055 S 32.31178 E Stream feeding into the Phongolo River	
Site number GPS coordinates Description	28 26.92345 S 32.31537 E Lukhondo pool	

Table 7.2. (continued)

Site number GPS coordinates Description	29 26.92831 S 32.3299 E Pan	
Site number GPS coordinates Description	30 26.86554 S 32.16415 E Matenini Pan	
Site number GPS coordinates Description	31 26.909436 S 32.313219 E Camp site	

Table 7.3. Specific sampling sites for amphibian survey outside Ndumo Game Reserve.

Site number GPS coordinates Description	32 27.05713 S 32.23254 E Road side borrow pit	
Site number GPS coordinates Description	33 27.00393 S 32.28150 E Temporary pan for rainy season	
Site number GPS coordinates Description	34 27.00785 S 32.28811 E Well vegetated pool	
Site number GPS coordinates Description	35 27.00572 S 32.28936 E Permanent pan used for livestock	
Site number GPS coordinates Description	36 26.98893 S 32.26902 E Small natural spring	

7.2.4 Birds

Site selection: The Ndumu Game Reserve is well known for its high bird diversity, with more than 400 species already recorded. Initial riverine site selection was done from satellite views with as much habitat variety as possible. A reconnaissance survey of the Ndumo Game Reserve was then undertaken and the vegetation and habitat types were noted in order to select sites suited to the aims of the project. Five sites along the river were then selected for biodiversity surveys, based on accessibility, personal safety, and suitability for point counts, and their GPS locations noted (Figure 7.3). Photographs were taken of the northern, eastern, southern and western view of each of the four plots in each of the five sites. Impacts, (perceived anthropogenic changes such as felled trees, etc.) if present, were noted and a general site description recorded.

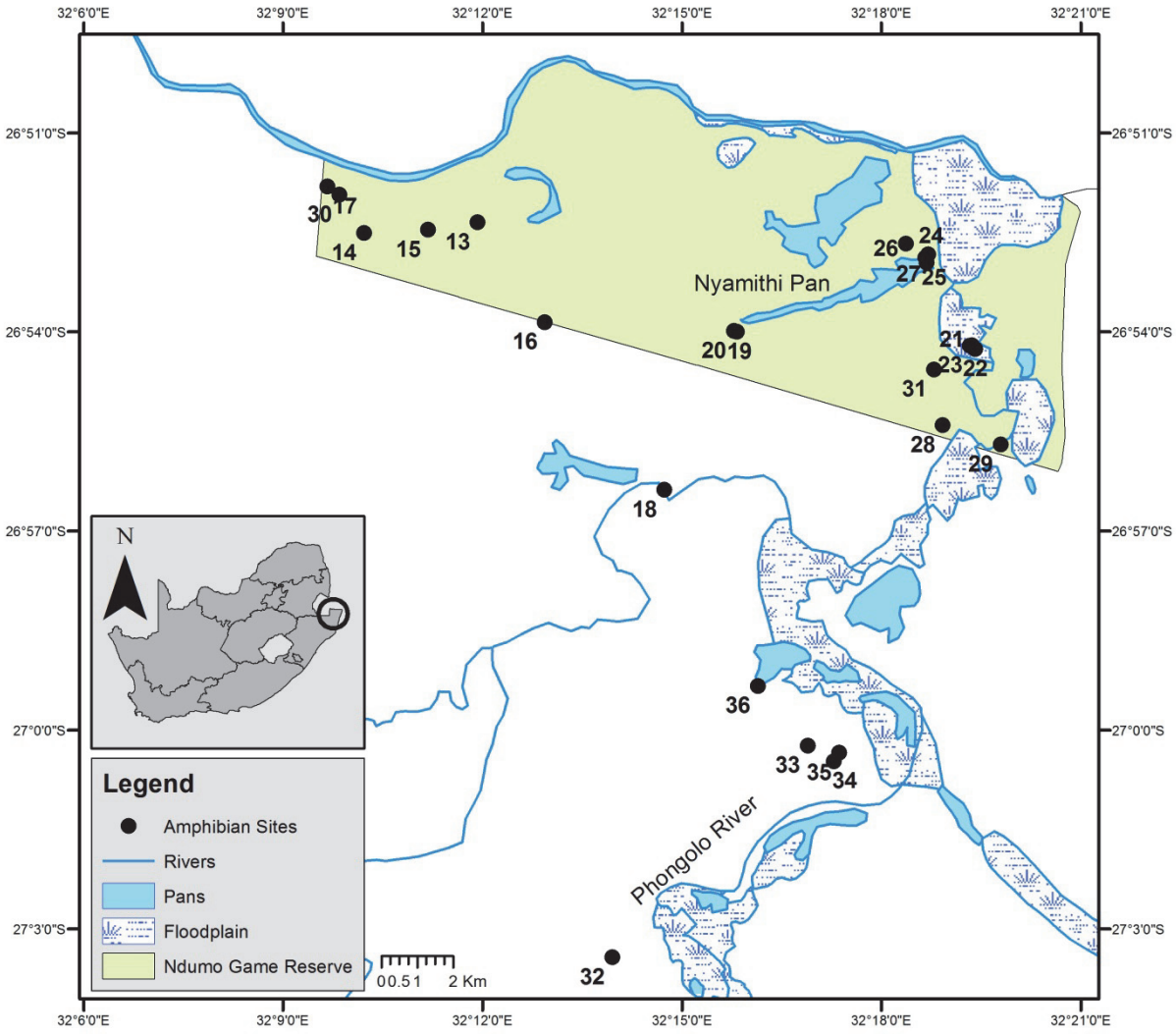


Figure 7.3. Ndumo Game Reserve with the sites indicated where the birds were studied.

Bird counts: Five sites with four plots in each site were selected. The plots were 100-150 m away from each other in order to eliminate pseudo-replication. The dense vegetation was assumed to limit bird movements between sites during the observations and the potential for double counting was deemed negligible. Sites were reached by vehicle, parking at least 200 m from the first plot and surveying was done on foot. After arriving at the first plot, a settling period of two minutes was allowed. At each plot, birds were identified by sight and sound for 10 minutes per plot within a radius of 50 m, and recorded. The date, time, site, plot number, bird species, and number of individuals were noted. These data were then read into Excel datasheets when back at the camp in order to do data analysis. Surveys were done in the early mornings and late afternoons (sunrise and sunset), to coincide with peak bird activity. No surveys were done during exceptionally windy conditions as bird activity is at a minimum then.

Data analyses: In most cases an NMDS ordination of species and number of individuals was done. Non-metric multidimensional scaling (NMDS) was selected as the best model as it avoids the assumption of linear relationships among variables by using ranked distances to linearise the relationships between measured distances in ordination space. NMDS deals much better with zero (equivalent to absences) compared with other ordination methods. The distance measure used was Relative Sørensen. The analysis parameters allowed for up to six axes, with 500 iterations during calculations. Random starting configurations were used with 250 runs of real data and 250 runs of randomised data. In some cases, PCAs were done, as the data were not amenable to NMDS ordination. Species with three or fewer individuals (occurrences) were excluded from the calculations as they contribute little to overall interpretation.

Site description: All the sites were situated within a 3 km radius of each other (Figure 7.3). Sites were mostly dense, with riverine forest and riverine bush the most abundant vegetation and habitat.

- **Site 37 (Oosgrens) (26º55'47.04"S, 32º19'30.33"E)**: The river runs on the south-eastern side of this site, with informal settlements across the river. This site has many tall trees, mainly wild fig trees. Young saplings and bushy vegetation are prominent, with vines and creeping vegetation making it thick riverine bush. The many tall trees are close together, resulting in quite a high, closed canopy. Grass is sparse, very few forbs present and no reeds. Anthropogenic disturbances observed: trees are felled and burned, grass uprooted and houses built. Cattle graze the land, and croplands were observed right up to the edge of the river (Figures 7.4 and 7.5).



Figure 7.4. Google Earth image of Site 37 (Oosgrens) showing the dense riverine forest inside Ndumo Game Reserve, compared to sparsely vegetated land south and east of the reserve's border.



Figure 7.5. Photos indicating the dense vegetation at Site 37.

- **Site 38 (pump house) (26º54'18.88"S, 32º19'28.84"E)**: The river runs on the eastern side of this site. The vegetation of this site is similar to that of Site 37, with tall wild fig trees being the most prominent fixture and abundant in numbers. The leaf canopy is closed with very few gaps for sunshine. Fewer shrubs cover the ground than at Site 37, with little to no grass present and no reeds. Anthropogenic disturbances observed: little visible, although deeper in on the eastern side of the river trees are being felled (Figures 7.6 and 7.7).



Figure 7.6. Google Earth image of Site 38 (pump house).



Figure 7.7. Images of the vegetation at Site 38.

- **Site 39 (Buffelsrivier) (26º53'10.43"S, 32º18'59.46"E)**: The river is located on the south-eastern side of this site. There are fewer trees than in the previous sites, mostly open grass veld and reeds beds. A few tall trees were present, with a patch of very thick, dense, but short river bush. Grass was short and reeds were abundant, with steep river banks and some shrubbery on the bank. No anthropogenic disturbances could be discerned (Figures 7.8 and 7.9).



Figure 7.8. Google Earth image of Site 39 (Buffelsrivier).



Figure 7.9. Images of the vegetation at Site 39.

- **Site 40 (causeway) (26º52'58.45"S, 32º18'44.46"E)**: The river is located on the northern side of this site, with Nyamithi Pan just downstream and a few other small pans close by. Tall trees and thick riverine bush right on the river banks, with short grass more inland from there. One spot with thick reed beds stands out as the only reeds in that area along the river; however, a thick patch of reeds occurs closer to the pan (still within the site's radius). Raffia palms are abundant. Anthropogenic disturbances observed: a low-water concrete bridge runs through one subplot on the other side of the river. A bird hide is also close by (Figures 7.10 and 7.11).



Figure 7.10. Google Earth image of Site 40 (causeway).



Figure 7.11. Image of the vegetation at Site 40.

- **Site 41 (Nyamithi) (26º53'53.97"S, 32º16'10.32"E)**: This site was situated next to a pan and the river running into the pan is on the eastern side of the pan. Large open spaces with grass and a few tall fever trees dominated this area. Thick bushveld with medium sized trees and dense shrubbery were observed about 30 m from the river, with the most prominent vegetation being grass (ranging from short to about 50 cm tall). Wide mud flats occur, with riverine bush almost completely absent except for a few scattered shrubs. Anthropogenic disturbances observed: a two-track gravel road along the edge of the bushveld (Figures 7.12 and 7.13).



Figure 7.12. Google Earth image of Site 41 (Nyamithi).



Figure 7.13: Images of the vegetation at Site 41.

7.3 Results and discussion

7.3.1 Macroinvertebrates

Diversity of macroinvertebrates observed

Macroinvertebrates collected during the course of the present study are presented in Appendix 1.

Introduction and conservation status (IUCN Red List) of freshwater molluscs

There are no known threatened molluscs within the study area, although the KZN northern coastal region adjacent to the study area supports populations of two threatened species, *Septaria borbonica* and *S. tessellaria* (Figure 7.14). As no data are available on the

distribution of these species in the study area, it is believed that they could also be found in the Phongolo River system. Both have very limited known distributions, being restricted to the lowest reaches of rivers along the coast of KZN and possibly Mozambique, such as the Lower Phongolo River. The rapid increase in population density and habitat degradation in northern KZN is an important reason for the threatened status of these two species (Darwall *et al.* 2008). Two endemic mollusc species are found within the study area.

Threats to freshwater molluscs

Alien invasive species pose a serious threat to native freshwater molluscs. Invasive mollusc species such as *Tarebia granifera* (Figure 7.14), in particular, as well as *Lymnaea columella* and *Physa acuta* are impacting indigenous species such that the ranges of the native species are decreasing. *Tarebia granifera*, which is rapidly colonising freshwater and estuarine systems in northern KZN, is affecting the distribution of *Melanoides tuberculata* due to competition for food, while *Lymnaea columella* is affecting *L. natalensis* and *Physa acuta* is affecting *Bulinus africanus*. The interaction between invasive and indigenous snails needs urgent attention. Although *T. granifera* has not yet been reported from the Phongolo River system, it is expected that it will also become an invasive species in this system (Miranda & Perissinotto, 2014).

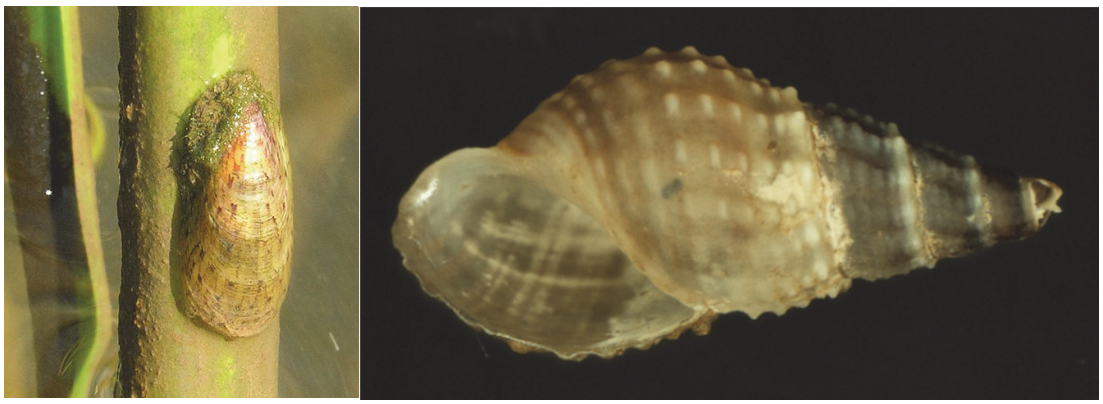


Figure 7.14. *Septaria tessellaria* on the left and *Tarebia granifera* on the right.

Introduction and conservation status (IUCN Red List) of dragonflies (Odonata)

The southern African region has a total of 293 dragonfly species (Darwall et al., 2008). The majority of species (146) are categorised as Least Concern, while 0.4%, 1.5% and 3.7% are categorised as Critically Endangered, Endangered and Vulnerable, respectively. Of these, at least 70 have distributions that include the Lower Phongolo River. These include at least nine endemic species.

In northern KZN and southern Mozambique, four species are thought to have restricted ranges. Of these, *Pseudagrion inopinatum* (EN) and *Pseudagrion celeste and Pseudagrion umsingaziense* (VU) are threatened and are believed to have highly restricted ranges within habitats which are declining.

Threats to dragonflies

The following are regarded as major threats to dragonfly diversity in the Lower Phongolo River system:

- **Wetland habitat degradation and loss**: Wetlands are generally poorly protected and the important and biological resources of these ecosystems are rapidly being lost through clearance and overuse.
- **Impoundments and water abstraction:** A major impact of dam construction is the loss of riverine habitats and alteration of downstream flow regimes
- **Deforestation:** Riverine forests are an important habitat for many Odonata species that need shade. Loss of riparian vegetation reduces available riverine habitat.
- **Pollution**: The increasing use of pesticides in the lowland areas where intensive agriculture is practised is posing a serious threat to the dragonfly population.
- **Invasive fish species**: Invasive fish species, such as bass, can adversely affect Odonata larval populations.

Introduction and conservation status (IUCN Red List) of freshwater crabs

Freshwater crabs (Potamonautidae, Potamoidea) are among the most important invertebrates inhabiting southern African freshwaters, with all 19 species found in the southern African region belonging to a single genus, *Potamonautes* (Darwall et al*.,* 2008) (Figure 7.15). Only one species has been recorded from the Phongolo floodplain and Maputaland, namely *Potamonautes sidneyi,* while *Potamonautes lividus* is also expected to inhabit the floodplain (Allanson, 1980).

Of the 19 species, only one (*P. lividus*) (5%) is listed in a threatened category (Vulnerable, VU). The blue river crab, *Potamonautes lividus,* is endemic to swamp forests in north-eastern KZN which may include the Lower Phongolo River system. These swamp forests are dominated by *Barringtonia racemosa*, *Ficus trichopoda* and *Syzygium cordatum.* The current known distribution of the species includes swamp forest areas in north-eastern KZN just south of the Phongolo system. Lack of information on freshwater crab populations in the study area precludes any conclusive statement on the distribution of the species in the

Phongolo system. Currently, populations of this crab are found in protected areas such as the Mkuze Game reserve.



Figure 7.15 *Potamonautes* sp.

Threats to freshwater crabs

The following factors are regarded as threats to the diversity of freshwater crabs in the Lower Phongolo River System:

- **Wetland habitat degradation and loss**: Wetlands in the Lower Phongolo River floodplain are generally heavily exploited for water abstraction, domestic use, and agricultural activities.
- **Natural predators:** Freshwater crabs are the largest of the macroinvertebrates in African aquatic ecosystems and when conditions are right can dominate benthic invertebrate communities. Freshwater crabs also form an integral part of the food chain in the river systems of southern Africa because they are vital components of the diet of a number of natural mammalian and avian predators. Freshwater crabs are important members of freshwater communities in the aquatic ecosystems of southern Africa, and it is vital to the health of these ecosystems that measures be considered that specifically include the conservation of local populations of river crabs.
- **Invasive competitors:** Like freshwater crabs, freshwater crayfish are dominant macroinvertebrates in freshwater habitats, and both of these crustaceans are potential niche competitors. In Africa, crabs and crayfish are not naturally in competition because crayfish are not naturally found in any part of this continent. Three of the four exotic freshwater crayfish species introduced into South Africa are thought to have the potential for a large impact on southern African freshwater ecosystems in general, including negatively affecting freshwater crab populations (De Moor, 2002). The recent discovery of the redclaw crayfish, *Cherax quadricarinatus,* in

the Usutu and Lower Phongolo Rivers is expected to have serious consequences for native freshwater crab populations in the system.

- **Pollution:** Rivers and wetlands are the ultimate receptacles for pollutants from river catchments. These pollutants impact freshwater crabs because they are benthic feeders that ingest invertebrates and detritus, which often contain high levels of contaminants.

The alien invasive redclaw crayfish (*Cherax quadricarinatus)*

The redclaw crayfish (*C. quadricarinatus*) (Figure 7.16) is a freshwater crayfish native to parts of northern Australia and Papua New Guinea. It is a fast-growing gregarious species, is tolerant of a broad range of environmental conditions and withstands wide variations in temperature, pH, and dissolved oxygen concentrations. It also shows tolerance to salinity concentrations of as high as 12 mg/L for extended periods. Its hardiness, flexible diet and fast growth were attractive to the aquaculture industry and it has been introduced worldwide as an economically important aquaculture and ornamental trade species (Snovsky & Galil, 2011; Du Preez & Smit, 2013). Redclaws benefit from a host of physical, biological and commercial attributes that make them excellent candidates for aquaculture. It is physically robust with broad geographic potential, has a simple life-cycle and straightforward production technology, requires low levels of dietary protein and is economic to produce. Its texture and flavour compare very favourably with commonly eaten marine crustaceans and, having the appearance of a lobster, is positioned at the premium end of the crustacean market spectrum.

The redclaw crayfish has established feral populations outside of its native distribution. It is widely recognized as an invasive species and feral populations are known to have established in South Africa, Mexico, Jamaica, Puerto Rico and Singapore (Ahyong & Yeo, 2007; Snovsky & Galil, 2011). Like many freshwater pest fish, once populations of redclaw have become established, eradication is almost impossible. Recently, the redclaw crayfish has been recorded in Lake Kariba and downstream areas of the Zambezi River. Reports in local Zimbabwean newspapers state that the crayfish is breeding out of control in northern Lake Kariba, devouring the food sources of other fish and putting the nation's entire aquatic ecosystem at risk.



Figure 7.16. *Cherax quadricarinatus* male.

In South Africa, reports indicate that the distribution of the species is increasing. An extensive uncultivated population has been found in the Nkomazi region of Mpumalanga, an area adjacent to the Mzinti Stream, a tributary of the Komati River. De Moor (2002) also reported that naturalised populations of the redclaw exist just across the Swaziland border at the Sand River Dam, which also drains into the Komati River. The existing breeding colony in this area is reportedly gradually spreading from the Sand River Dam into nearby irrigation canals and from there into the Komati River catchment.

During the present study, specimens of the redclaw crayfish were collected in the Usutu River (Site 6) and at the outlet of the Nyamithi Pan (Site 7) on the Phongolo River. These are the first records of the redclaw crayfish in the Usutu-Phongolo River system. The potential for the crayfish to spread and colonise the Phongolo floodplains is therefore highly probable and a matter of great concern (Du Preez & Smit, 2013). Similarly, the potential exists for the species to establish downstream in Mozambique.

Redclaw naturally inhabit a diversity of freshwater habitats including still ponds, small streams, isolated rock pools and fast-flowing rivers. Redclaw are omnivorous with a diet that includes small invertebrates and aquatic plants. In their natural habitat, redclaw are a relatively non-aggressive, non-burrowing species. However, observation of introduced populations and within the aquarium trade, indicate that this species can display aggressiveness and burrowing habits.

Redclaw have the potential to impact aquatic ecosystems through modification of natural habitats, direct predation, competition with native species and the introduction of crayfish diseases (Ahyong & Yeo, 2007). The translocation of freshwater crayfish into novel environments raises the possibilities of ecological impacts such as competitive interactions between the introduced and endemic species, food web perturbations, habitat alterations

and disease introductions. Numerous studies of introduced freshwater crayfish in Europe and North America show that they have negatively impacted native fauna and flora including macrophytes, other macroinvertebrates (especially gastropods), amphibians and fishes. Redclaw crayfish were also shown to dominate local Australian crayfish and prawn species.

The potential impact of *C. quadricarinatus* in southern Africa includes the destruction of aquatic macrophytes, resulting in effects on ecosystem functioning, disturbance of breeding of bottom-spawning fish, impacts on benthic macroinvertebrate communities and finally, the introduction of undesirable associated organisms, such as parasites and symbiotic microbes (De Moor, 2002). Culture experiments combining tilapia and redclaw crayfish found significantly reduced survival, food conversion, and final weight of tilapia cultured with redclaw crayfish present compared to culture without (De Moor, 2002). The warmer regions of South Africa are likely to be more susceptible to the negative impacts of an invasion, most specifically the Lowveld Ecoregion and Maputaland (thus including the Ndumo Game Reserve).

With regard to the National Environmental Management Biodiversity Act 2004, which provides an updated list of invasive species, *C. quadricarinatus* is regarded as a Category 1d invasive species: “invasive species that require control by means of an invasive species management programme”.

Like other crayfish, *C. quadricarinatus* is also a potential disease vector as host to numbers of parasitic or symbiotic microbes and invertebrates (Ahyong & Yeo, 2007; Du Preez & Smit, 2013). Parasites and diseases of Australian crayfish are not fully known nor are their impacts fully understood. There are several diseases and/or parasites specific to redclaw crayfish. Recently, Du Preez and Smit (2013) reported that the redclaw crayfish recorded in the Usutu and Phongolo Rivers were infected with a non-indigenous temnocephalan flatworm parasite, *Diceratocephala boschmai*. To date no record exists of any natural populations of any temnocephalans in Africa. It is feared that the non-host-specific temnocephalan might transfer to local decapods, such as freshwater crabs, causing a large-scale infection in local species.

Other freshwater crayfish species

De Moor (2002) reviewed the presence of four exotic freshwater crayfish species in South Africa, *Cherax destructor*, C. *quadricarinatus, C. tenuimanus and Procambarus clarkia*. Of these, only *C. tenuimanus* was regarded as not being a potential serious threat to freshwater ecosystems in South Africa. The other three were all regarded as a serious threat to our ecosystems and that everything possible should be done to prevent an invasion. *Cherax*

destructor is known for digging deep holes into dam walls and river embankments, which might weaken these structures. They also eat eggs and small larvae of native fish and compete for space with indigenous shrimp species and crayfish.

7.3.2 Freshwater fish

Fish biodiversity

As part of the fish biodiversity study that included 5 surveys of 13 different sites in the Lower Phongolo (Chapter 2) a total of 3 348 individuals belonging to 37 fish species were collected (Table 7.4). The species diversity data were compared to historical data collected during 1974-1976, 1983, 1984 and 1993-1994 (Merron et al., 1993; Merron et al., 1994a-f). Interestingly, the number of species recorded over the different years (35 species in 1974-1976; 32 in 1983; 30 in 1984; 42 in 1993-1994; and 37 in the current study) has remained relatively constant but the species composition varied during this time. Species collected during 1974-1994 but not recorded during the current study include: *Barbus viviparus, Clarias ngamensis, Labeo congoro, Labeobarbus marequensis, Mesobola brevianalis, Microphis fluviatilis* and *Opsaridium peringueyi.* In addition a single species, *Oreochromis placidus*, was recorded during the present study that had not been recorded during the 1974-1994 surveys.

Fish community structures

In the early 1990s Merron et al. (1993; 1994a-f) did extensive fish sampling in the Lower Phongolo River and floodplain. A total of six surveys with three in high-flow and three in low-flow regimes were carried out. Where possible, the community structures of those studies were directly compared to these of the present study. Data from two surveys (April and July 1994) for Site 1 in the Phongolo River, a single survey (April 1994) for Site 6 in the Usutu River and four surveys (November 1993 and April, July and September 1994) for Site 7 (Nyamithi Pan) were comparable to data of the recent study. Historical results represent two surveys conducted during 1993 and 1994. During 1993 the dominant species at Site 1 (Table 7.5) was *M. acutidens* (44%) followed by *O. mossambicus* (31%). However, during the 1994 survey *O. mossambicus* was the dominant species followed by *G. callidus;* a total of 499 individuals were caught comprising 12 species. During the 2013 survey *M. acutidens* (59%) were the dominant species again, followed by *T. sparrmanii* (17%); a total of 109 individuals were caught comprising 11 species. In 1993 Site 1 was largely populated by *G. callidus* (51%) followed by *O. mossambicus* (20%) and a total of 173 individuals were caught comprising eight species. During 2013 the site was dominated by *T. sparrmanii* (40%) followed by *G. callidus* (38%) with a total of 108 individuals comprising seven species.

Table 7.4. Comparative species list of the fishes collected from the Lower Phongolo River and floodplain (data from Merron et al., 1993; 1994a-f; and present study (2012-2014)).

Species	Abbrev.	1974-6	1983	1984	1993-4	2012-14
Alestidae						
Brycinus imberi (B. lateralis)	BIMB	x	x	x	x	x
Hydrocynus vittatus	HVIT	x	x	x	x	x
Micralestes acutidens	MACU	x	x	x	x	x
Anguillidae						
Anguilla bengalensis labiata (A. nebulosa)	ALAB	x	x		x	x
Anguilla bicolor bicolor	ABIC	x	x		x	x
Anguilla marmorata	AMAR	x	x		x	x
Anguilla mossambica	AMOS	x		x	x	x
Cichlidae						
Coptodon rendalli (Tilapia rendalli)	TREN	x	x	x	x	x
Oreochromis mossambicus	OMOS	x	x	x	x	x
Oreochromis placidus	OPLA					x
Pseudocrenilabrus philander	PPHI	x	x	x	x	x
Tilapia sparrmanii	TSPA	x	x	x	x	x
Clariidae						
Clarias gariepinus	CGAR	x	x	x	x	x
Clarias ngamensis	CNGA	x	x	x	x	
Cyprinidae						
Barbus afrohamiltoni	BAFR	x	x	x	x	x
Barbus annectens	BANN	x	x	x	x	x
Barbus pallidus	BPAL				x	x
Barbus paludinosus	BPAU	x	x	x	x	x
Barbus radiatus	BRAD	x	x	x	x	x
Barbus toppini	BTOP	x	x	x	x	x
Barbus trimaculatus	BTRI	x	x	x	x	x
Barbus unitaeniatus	BUNI				x	x
Barbus viviparus	BVIV	x	x	x	x	
*Cyprinus carpio**	CCAR				x	x
Labeo congoro	LCON	x	x	x	x	
Labeo cylindricus	LCYL	x	x	x	x	x
Labeo molybdinus	LMOL	x	x	x	x	x
Labeo rosae	LROS	x	x	x	x	x
Labeobarbus marequensis	BMAR	x	x			
Mesobola brevianalis	MBRE	x	x	x	x	
Opsaridium peringueyi (zambezense)	OPER				x	
Cyprinodontidae						
Nothobranchius orthonotus	NORT	x			x	x
Gobiidae						
Awaous aeneofuscus	AAEN				x	x
Glossogobius callidus	GCAL				x	x
Glossogobius giuris	GGIU	x	x	x	x	x
Redigobius dewaali	RDEW	x	x	x	x	x
Megalopidae						
Megalops cyprinoides	MCYP				x	x
Mochokidae						
Chiloglanis paratus	CPAR	x		x	x	x
Chiloglanis swierstrai	CSWI	x	x	x	x	x
Synodontis zambezensis	SZAM	x	x	x	x	x
Mormyridae						
Marcusenius macrolepidotus	MMAC	x	x	x	x	x
Petrocephalus wesselsi (P. catostoma)	PCAT	x	x	x	x	x
Schilbeidae						
Schilbe intermedius	SINT	x	x	x	x	x
Syngnathidae						
Microphis fluviatilis	MFLU				x	
Total no. of species		35	32	30	42	37

During the 1994 survey, Site 6 (Usutu River) was dominated by *B. annectens* (21%) followed by *O. mossambicus* (14%) (Table 7.6). A total of 198 individuals were caught comprising 17 species. During 2013 Site 6 was dominated by *O. mossambicus* (28%) closely followed by *M. acutidens* (27%). A total of 83 individuals were caught comprising 14 species.

Table 7.5. Comparison of historical (1993) vs. present (2013) community structures of fish at Site 1 (Phongolo River) during the April (a) and July (b) surveys (low flow).

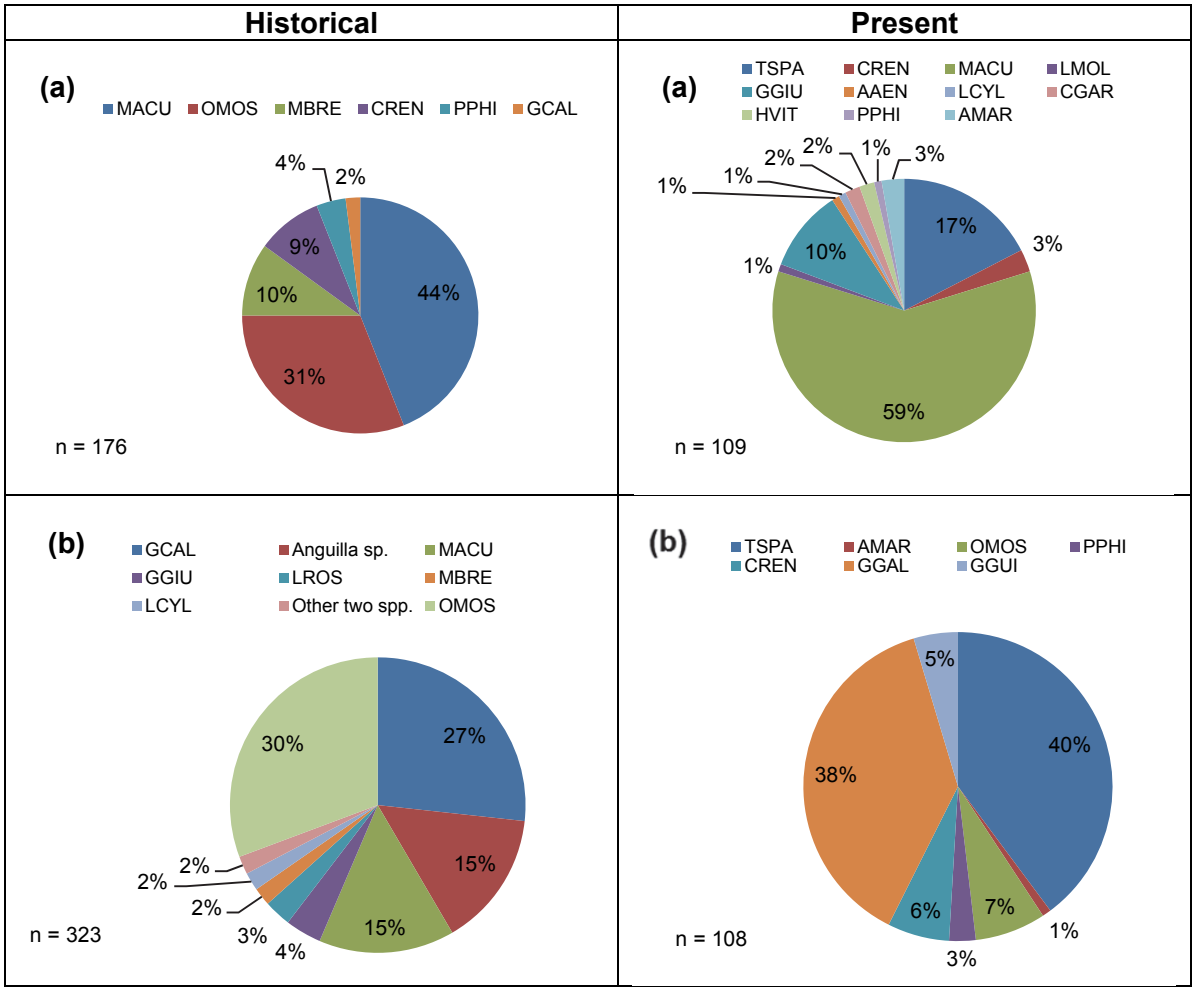
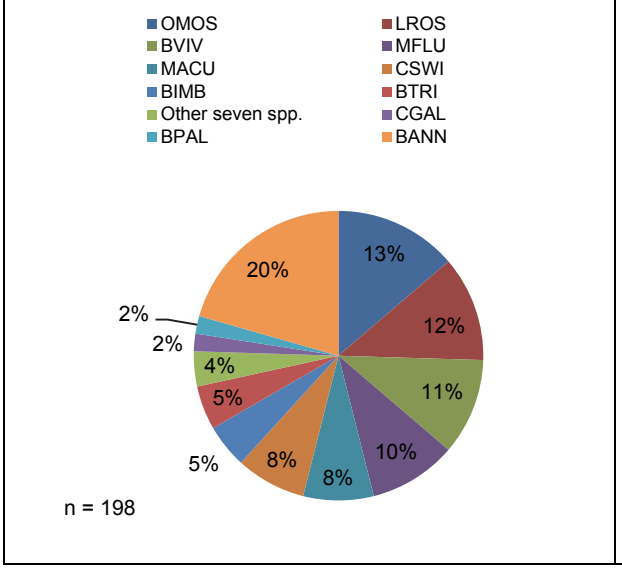
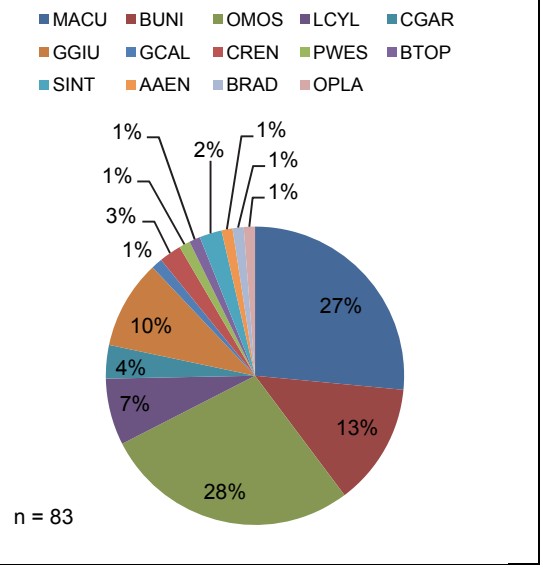


Table 7.6. Comparison of historical (April 1994) vs. present (April 2013) community structures of fish at Site 6.

Historical	Present
	

During November 1993 at Site 7 (Nyamithi Pan), *O. mossambicus* (90%) were the dominant species followed by *Glossogobius* sp. (9%) with a total of 925 individuals comprising five species (Table 7.7 (a)). *Oreochromis mossambicus* (65%) dominated the November 2012 (Table 7.7 (a)) survey followed by *Coptodon rendalli* (20%) with a total of 208 individuals caught (five species). During the April 1994 survey two areas in Nyamithi Pan were sampled, namely a vegetated area (Table 7.7 (b1)) and a non-vegetated area (Table 7.7 (b2)). In both instances the dominant species were *O. mossambicus* (75% in vegetated area; 90% in non-vegetated area), followed by *G. callidus* (12% in vegetated area; 4% in non-vegetated area). A total of 532 individuals were caught comprising five species. Recent results indicate that during April 2013 (Table 7.7 (b1)) this pan was dominated by *C. rendalli* (50%) followed by *O. mossambicus* (38%). During April 2014 (Table 7.7 (b2)) *O. mossambicus* (49%) dominated the pan, closely followed by *C. rendalli* (44%). A total of 169 individuals were caught comprising four species. Site 7 was dominated by *O. mossambicus* (76%) during the 1993 survey followed by *C. rendalli* (17%) with 381 individuals comprising five species. The same species dominated this site during the 2013 survey with *O. mossambicus* (43%) and *C. rendalli* (37%). During September 1993 Merron et al. (1993) sampled most of the sites twice. One sampling survey was conducted before a scheduled flood release and another just after the flood release. The survey of Site 7 before the flood release yielded a total of 677 individuals comprising three species dominated by *O. mossambicus* (67%) followed by *G. callidus* (25%) and *C. rendalli* (12%). After the flood release a total of 566 individuals were caught comprising four species with the dominant species being *G. callidus* (98%). During the 2013 survey this site was dominated by *C. rendalli* (72%) and *O. mossambicus* (28%) and they were the only two species caught with a total of 47 fish.

Table 7.7. Comparison of historical (November 1993 (a), April 1994 (b 1) – vegetated and (b 2) – non-vegetated), July 1994 (c) and September 1994 (d) vs. the present (November 2012 (a), April 2013 (b 1) and 2014 (b 2), July 2013 (c) and September 2013 (d) community structures of fish surveyed at Site 7.

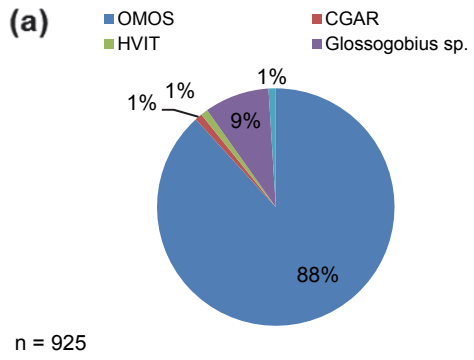
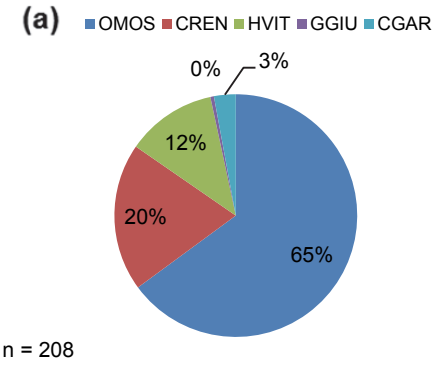
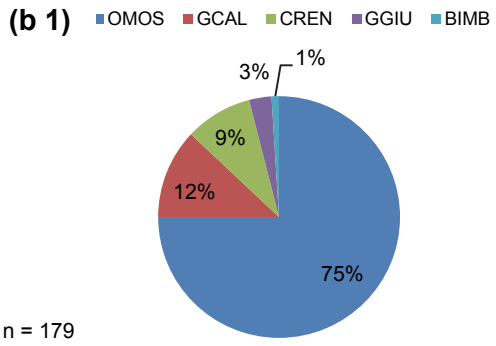
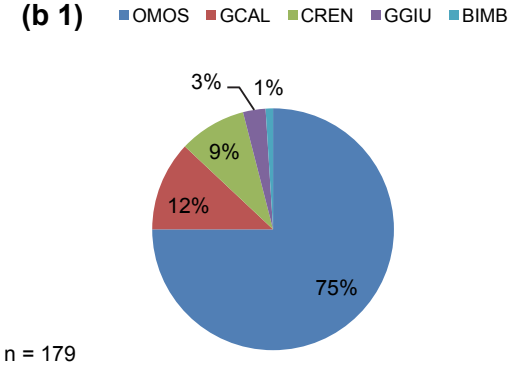
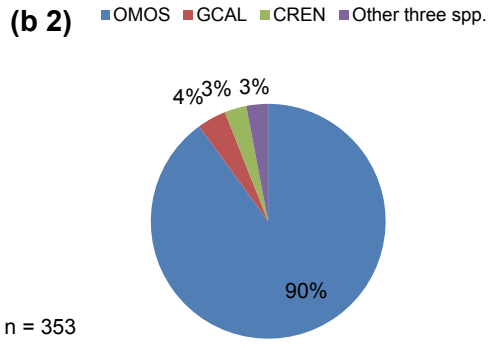
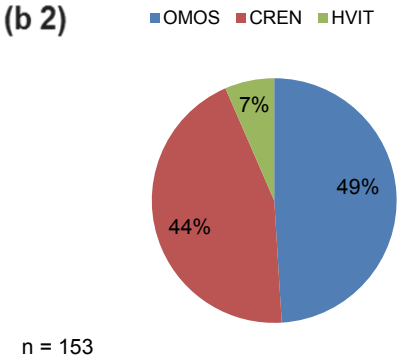
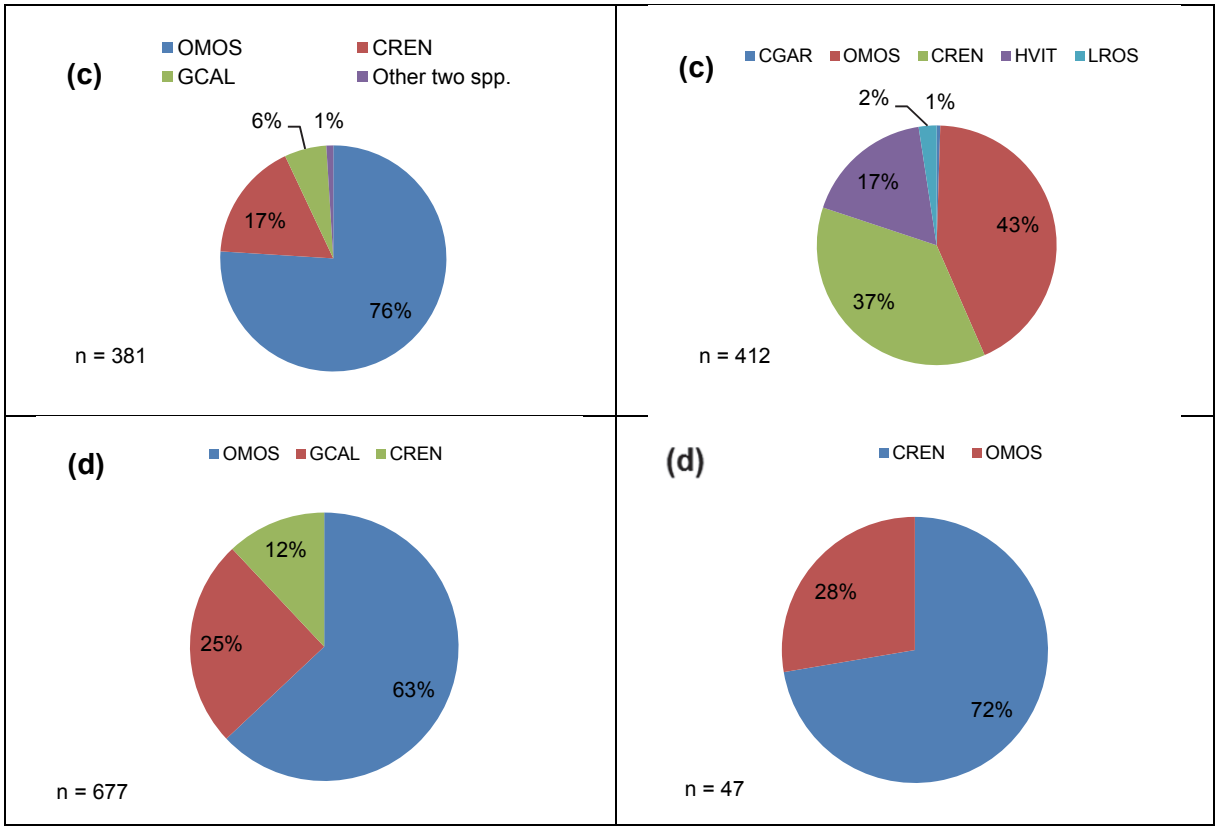
Historical	Present
	
	
	

Table 7.7. (continued)



A total of 62 individuals comprising nine species were collected during April 1994 at Site 11 (Nomaneni Pan) and dominated by the smaller fish species such as *B. annectens* (39%) and *P. philander* (19%). During 2013 a total of 142 individuals were caught comprising seven species and similarly dominated by *P. philander* (39%) followed by *T. sparrmanii* (30%). A year later (2014) a total of 41 individuals were caught comprising five species, but this time the dominant species was *O. mossambicus* followed by *T. sparrmanii* (37%). During the September 1994 survey Sites 11 and 12 were connected due to a very high flood release and a total of 13 individuals were caught comprising four species, with the most abundant species being *P. philander* (77%) (Table 7.8 (b)). During the 2013 survey these two sites were not connected (Table 7.8 (b 1) and (b 2)) and a total of 29 individuals comprising four species were collected from Site 11 (Table 7.8 (b 1)) with the most abundant species being *C. rendalli* (52%) followed by *T. sparrmanii* (38%). At Site 12 a total of 40 individuals comprising six species were caught with *B. trimaculatus* (55%) being the most abundant species followed by *B. annectens* (15%) (Table 7.8 (b 2)).

Table 7.8. Comparison (Sites 11 and 12) of historical (April (a) and September 1994) vs. present (April 2013 (a 1) and 2014 (a 2) and September 2013) community structures of fish.

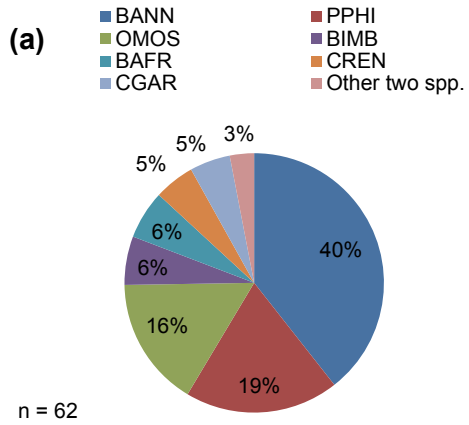
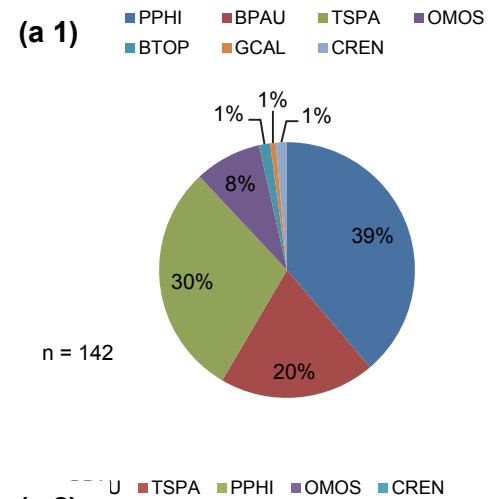
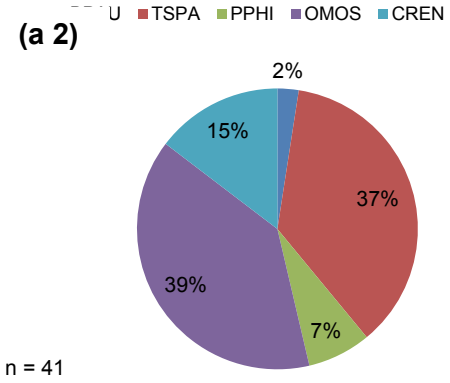
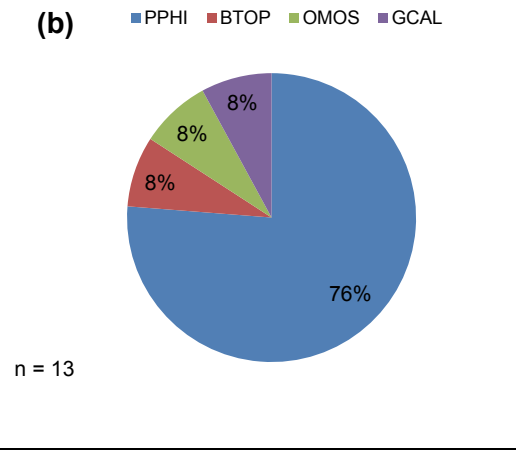
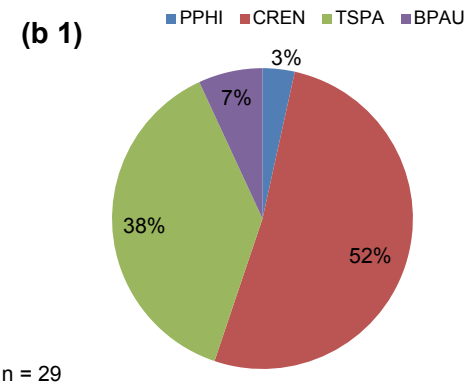
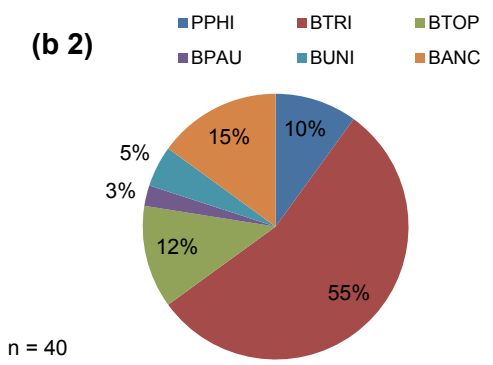
Historical	Present
	
	
	

Table 7.8. (continued)



Fish biodiversity and community structure

Historical data from April 1994 revealed that there was a large number of *M. acutidens, O, mossambicus, G. callidus* and *Anguilla* sp. present at Site 1 (Phongolo River) (Merron et al., 1994c). The dominance of these five species, however, has changed dramatically with only *O. mossambicus* and *G. callidus* now dominant. *Tilapia sparrmanii* has now established among the vegetated areas at this site. Of the original 12 recorded species at this site during high flow only 11 were sampled during the recent survey. *Mesobola brevianalis* was not observed at this site and this finding could be attributed to the irregular floods of previous years. The total number of fish decreased from 1994 to 2013, which could be attributed to the fact that rotenone was used during the 1994 survey.

During the 1994 survey 17 different species were recorded at Site 6 (Usutu River) and of those the most abundant were *Chiloglanis swierstrai, Barbus viviparus* and *Microphis fluviatilis* of which none were recorded during the 2013 survey. Of these species *M. fluviatilis* is of estuarine origin and is normally not found so far inland (Skelton, 2001). During the 2013 survey *O. placidus* was recorded which had not been recorded in any of the previous surveys.

During the 1994 low-flow survey of June 1994 at Site 7 (Nyamithi Pan), it was observed that *O. mossambicus* remained the dominant species in this pan, but the numbers of *C. rendalli* had increased significantly. When compared to the recent results, *O. mossambicus* remained the dominant species in this pan but the number of *C. rendalli* increased even more when compared to the high-flow season. Although more fish were caught during low flow in Nyamithi Pan, historical results indicate that there were more fish in the pan during 1994, because only 412 fish where caught with six hauls of a 35 m seine net when compared to 1994 when a total of 381 fish were caught in a single haul of a 25 m seine net.

This can be attributed to a number of factors, including the parasitic infestation, increased numbers of *H. vittatus* preying on *O. mossambicus* as well as a large number of crocodiles (*Crocodylus niloticus*). Ndumo Game Reserve supports one of South Africa's largest wild crocodile populations and after reaching a length of 120 cm they mainly feed on fish (Calverley, 2013).

During the September survey (low flow) of 1994 Merron et al. (1994e) carried out two surveys, one before a flood release and a second just after the flood release. The community structure of Site 6 (Nyamithi Pan) remained stable when compared to the previous low-flow survey (June 1994), although the number of fish were almost double. What raised concern is that after the flood release in August 1994 the large number of *O. mossambicus* and *C. rendalli* from the pan disappeared and *G. callidus* dominated the pan, representing 98% of the species composition. The total number of fish collected remained high with a total of 566 specimens sampled. The cause of this drastic change in community structure can possibly be attributed to the fact that the floods of 1994 could have dispersed the *O. mossambicus* and *C. rendalli* from the pan into the river below and replaced them with the *G. callidus* that where present in pools and pans further upstream. Results from the September 2013 survey indicated that the pan is dominated by *C. rendalli* during low-flow periods and that the numbers of fish are still declining with only 47 fish caught with three hauls of a 35 m seine net.

Site 11 (Nomaneni Pan) was historically dominated by small fish species such as *B. annectens* and *P. philander*. This remained the same during the 2013/4 surveys with the exception of *T. sparrmanii* and *O. mossambicus*. Both these species were not large and ranged between 30 and 60 mm. The reason for the lack of larger fish in this pan may be attributed to the local people utilising fish from this pan as their source of protein.

7.3.3 Amphibians

Data on frogs collected are presented in Table 7.9 and Table 7.10, comparing current population levels with the historical data (provided by Ezemvelo Wildlife). According to the historical data, a total of 39 different species have been documented (between 1929 and 2001) in the Ndumo Game Reserve and surrounds. Since the beginning of the present study in 2012 a total of 34 species have been documented (either through active sampling or acoustic surveys). Subsequently, a new locality has been recorded for the Mascarene grass frog (*Ptychadena mascareniensis*).

Table 7.9. Summary of the frog species and numbers of frogs collected during the various collection events with an indication of species historically collected.

Species per survey									
		Ndumo						Outside Ndumo	
SPECIES NAME	**Historical**	**Feb-12**	**Nov-12**	**Apr-13**	**Nov-13**	**Feb-14**		**Aug-12**	**Apr-13**
Arthroleptidae									
Arthroleptis stenodactylus	X								
Leptopelis mossambicus	X		6		2				
Brevicipitidae									
Breviceps adspersus	X				2	2			
Breviceps mossambicus	X								
Bufonidae									
Amietophrynus fenoulheti	X								
Amietophrynus garmani	X	1	7	16	4	1		5	2
Amietophrynus gutturalis	X		1		1			3	
Amietophrynus maculatus	X			9					
Schismaderma carens	X	4		1		1			
Hemisotidae									
Hemisus m. marmoratus	X			14	7	7			
Hyperoliidae									
Afrixalus aureus	X			11	5	7			
Afrixalus delicatus	X	6							
Afrixalus fornasini	X	2				1			
Hyperolius argus	X								43
Hyperolius m. taeniatus	X	15		20	5	13		6	12
Hyperolius poweri	X								
Hyperolius pusillus	X			1		15		3	1
Hyperolius tuberilinguis	X	10	13	7		6			
Kassina maculata	X					10			
Kassina senegalensis	X			7		2		4	

Table 7.9. (continued)

Microhylidae									
Phrynomantis bifasciatus	X					4			
Phrynobatrachidae									
Phrynobatrachus acridoides	X								
Phrynobatrachus mababiensis	X	2		6	13	1			
Phrynobatrachus natalensis	X								
Pipidae									
Xenopus laevis	X		3						
Xenopus muelleri	X	5	1	206	3	5			3
Ptychadenidae									
Ptychadena anchietae	X	11	14	26	18	9		1	
Ptychadena mascareniensis		4		1					2
Ptychadena mossambica	X	3		9	6	5			
Ptychadena oxyrhynchus	X		1						
Pyxicephalidae									
Amietophrynus rangeri	X								
Cacosternum boettgeri	X							10	30
Cacosternum nanum	X								
Hildebrandtia ornata	X	2		1	2	1			
Pyxicephalus edulis	X					15			
Strongylopus fasciatus	X								
Tomopterna cryptotis	X	1	2	2	3				
Tomopterna krugerensis	X	1							
Tomopterna natalensis	X			1					
Rhacophoridae									
Chiromantis xerampelina	X	15		39	15	3			1
		15	**9**	**18**	**14**	**19**		**7**	**8**

Table 7.10. Summary of the frog species collected per type of locality for the entire study period.

Species per site												
		Ndumo total						**Outside Ndumo**				
	SPECIES NAME	**Pan/ pond**	**Vlei**	**River/ stream**	**Lake**	**Terrestrial**		**pan/ pond**	**Vlei**	**River/ stream**	**lake**	**Terrestrial**
1	*Afrixalus aureus*	21	2	0	0	0		0	0	0	0	0
2	*Afrixalus delicatus*	6	0	0	0	0		0	0	0	0	0
3	*Afrixalus fornasini*	0	3	0	0	0		0	0	0	0	0
4	*Amietophrynus rangeri*	0	0	0	0	0		0	0	0	0	0
5	*Amietophrynus fenoulheti*	0	0	0	0	0		0	0	0	0	0
6	*Amietophrynus garmani*	10	2	5	1	11		1	0	5	0	1
7	*Amietophrynus gutturalis*	0	0	1	0	1		0	0	3	0	0
8	*Amietophrynus maculatus*	0	0	9	0	0		0	0	0	0	0
9	*Arthroleptis stenodactylus*	0	0	0	0	0		0	0	0	0	0
10	*Breviceps adspersus*	0	0	0	0	4		0	0	0	0	0
11	*Breviceps mossambicus*	0	0	0	0	2		0	0	0	0	0
12	*Cacosternum boettgeri*	0	0	0	0	0		25	0	15	0	0

Table 7.10 (continued)

13	*Cacosternum nanum*		0	0	0	0	0		0	0	0	0	0
14	*Chiromantis xerampelina*		53	1	18	0	0		1	0	0	0	0
15	*Hemisus m. marmoratus*		19	0	9	0	0		0	0	0	0	0
16	*Hildebrandtia ornata*		5	0	0	0	1		0	0	0	0	0
17	*Hyperolius argus*		0	0	0	0	0		43	0	0	0	0
18	*Hyperolius m. taeniatus*		25	18	0	10	0		12	6	0	0	0
19	*Hyperolius poweri*		0	0	0	0	0		0	0	0	0	0
20	*Hyperolius pusillus*		1	15	0	0	0		1	3	0	0	0
21	*Hyperolius tuberilinguis*		8	8	10	10	0		0	0	0	0	0
22	*Kassina maculata*		0	10	0	0	0		0	0	0	0	0
23	*Kassina senegalensis*		9	0	0	0	0		0	4	0	0	0
24	*Leptopelis mossambicus*		2	1	5	0	0		0	0	0	0	0
25	*Phrynobatrachus acridoides*		0	0	0	0	0		0	0	0	0	0
26	*Phrynobatrachus mababiensis*		20	0	2	0	0		0	0	0	0	0
27	*Phrynobatrachus natalensis*		0	0	0	0	0		0	0	0	0	0
28	*Phrynomantis bifasciatus*		3	0	0	0	1		0	0	0	0	0
29	*Ptychadena anchietae*		42	0	35	0	1		0	1	0	0	0
30	*Ptychadena mascareniensis*		5	0	0	0	0		2	0	0	0	0
31	*Ptychadena mossambica*		21	0	0	0	2		0	0	0	0	0
32	*Ptychadena oxyrhynchus*		0	1	0	0	0		0	0	0	0	0
33	*Pyxicephalus edulis*		8	7	0	0	0		0	0	0	0	0
34	*Schismaderma carens*		5	0	0	0	1		0	0	0	0	0
35	*Strongylopus fasciatus*		0	0	0	0	0		0	0	0	0	0
36	*Tomopterna cryptotis*		2	0	0	0	6		0	0	0	0	0
37	*Tomopterna krugerensis*		0	0	0	0	1		0	0	0	0	0
38	*Tomopterna natalensis*		1	0	0	0	0		0	0	0	0	0
39	*Xenopus laevis*		3	0	0	0	0		0	0	0	0	0
40	*Xenopus muelleri*		213	0	7	0	0		3	0	0	0	0
			482	**68**	**101**	**21**	**31**		**9**	**4**	**3**	**0**	**1**

For the period April-July 2013 no frog calls were recorded by the song meter. The first recorded frog call was that of the guttural toad *Amietophrynus gutturalis* during August 2013, followed by four species in September. Call activity peaked in December with 12 species calling. Analysis of the song meter recordings revealed that over a period of one year the calls of 17 species were recorded.

Table 7.11. Frogs detected through passive acoustic monitoring (PAM) for the period August 2013 to April 2014. Cells in light grey shading indicate a small chorus, cells in dark grey shading indicate a moderate chorus and cells in black shading indicate a large chorus.

TAXON NAME	FAMILY	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14
Afrixalus aureus	Hyperoliidae									
Afrixalus delicatus	Hyperoliidae									
Amietophrynus garmani	Bufonidae									
Amietophrynus gutturalis	Bufonidae									
Cacosternum nanum	Pyxicephalidae									
Chiromantis xerampelina	Rhacophoridae									
Hemisus marmoratus	Hemisotidae									
Hyperolius marmoratus	Hyperoliidae									
Kassina maculata	Hyperoliidae									
Kassina senegalensis	Hyperoliidae									
Leptopelis mossambicus	Arthroleptidae									
Phrynobatrachus mababiensis	Phrynobatrachidae									
Phrynobatrachus natalensis	Phrynobatrachidae									
Phrynomantis bifasciatus	Microhylidae									
Ptychadena anchietae	Ptychadenidae									
Ptychadena mossambica	Ptychadenidae									
Tomopterna cryptotis	Pyxicephalidae									

Throughout this project a high amphibian species diversity (Tables 7.9-7.11) and richness have been documented within the Ndumo Game Reserve. This is most likely as a result of the diversity of available and suitable microhabitats for amphibians. Ndumo Game Reserve has a large number of pans varying in degree of seasonality, inundation and water depth. This diversity caters for the variety of frog species. The small pans outside the reserve that were sampled were severely altered by anthropogenic activities and this was reflected in the low number of species detected. The biggest impact was by cattle utilizing pans and in the process trampling the area and eventually destroying all the vegetation.

Potential threats

Amphibian flatworm parasites

Screening for flatworms revealed that both *Xenopus muelleri* and *Ptychadena anchietae* are infected with, respectively, *Protopolystoma orientalis* and *Polystoma dawiekoki.* The prevalence of these infections was quite low and these infections pose no threat to the amphibian populations.

Amphibian blood parasites

Although blood samples were obtained (Table 7.12) for all frog species collected, we decided to focus our attention first on the family Bufonidae. Blood samples taken for this specific family were screened for blood parasites including *Trypanosoma*, *Haemogregarina* and microfilaria. Slides containing infected blood samples were marked and all different morphotypes were photographed. Where ± 25 individuals were photographed, blood parasites were then measured according to Cook et al. (2009) (see Figure 7.17). The mean, standard deviation, minimum and the maximum of each individual blood parasite was calculated.

Table 7.12. List of all the frog species found to be infected with different blood parasites in and around Ndumo Game Reserve.

Frog species	**Number examined**	**Number infected**	**Hepatozoon sp.**	**Dactylosoma sp.**	**Viral or viral-like organisms**	**Trypanosoma sp.**	**Microfilariae**
			P; I	**P; I**	**P; I**	**P; I**	**P; I**
Amietophrynus garmani	30	7	4/7; 8.4%			2/7; 21 p/s	
Amietophrynus gutturalis	4	3	3/8; 2.4%				
Amietophrynus maculatus	9	7	7/7; 19.5%			3/7; 3 p/s	
Chiromantis xerampelina	44	1				1/1;26 p/s	
Hemisus marmoratus	22	2	2/2; 0.8%				
Hildebrandtia ornata	6	1	1/1; 0.3%				
Hyperolius marmoratus taeniatus	36	4	3/36; 20.5%			1/1; 1 p/s	
Hyperolius tuberilinguis	12	1				1/1; 20 p/s	
Kassina maculata	8	1				1/1; 4 p/s	
Phrynobatrachus mababiensis	13	1	1/1; 0.3%			1/1; 8 p/s	
Phrynomantis bifasciatus	1	1				1/1; 6 p/s	
Ptychadena anchietae	78	47	31/47; 2.4%	13; 1%	4/47; 75%	29/47; 13.3 p/s	1/47; 1 p/s
Ptychadena mascareniensis	5	2	1/2; 0.2%			2/2; 8.8 p/s	
Ptychadena mossambica	19	7	5/7; 3%		2/7; 99%	4/7; 6 p/s	
Schismaderma carens	7	2	1/2; 0.8%				1/2; 28 p/s
Total: 15	**436**	**87**					
Prevalence = P; Intensity = I ; Per-slide = p/s							

Both mature and immature gamonts were observed. Mature gamonts had a well-developed capsule while immature gamonts with a small capsule were observed, if present at all.

Mature gamonts: oval-shaped with a slight gap/cavity at the anterior pole (Figure 7.17 A-C); seems to contain a thick parasitophorous vacuole with the capsule measuring 14.2 ± 0.77 µm (12.23-16.53) long by 11.82 ± 2.44 µm (7.99-14.25) wide (n = 102); capsule excluding gap measured 11.82 ± 2.44 µm (7.99-14.25) long, width remains the same. In some cases a small recurved tail can be seen. Whitish-blue-purple stained cytoplasm sometimes with pink-purple stained granules; irregularly oval-shaped, blue or purple stained nucleus measuring 3.90 ± 1.20 µm (2.58-5.90) long by 4.01 ± 1.05 µm (1.44-5.54) wide; in some cases the gamont would cause the nucleus to split (Figure 7.17b) (Cook et al., 2009).

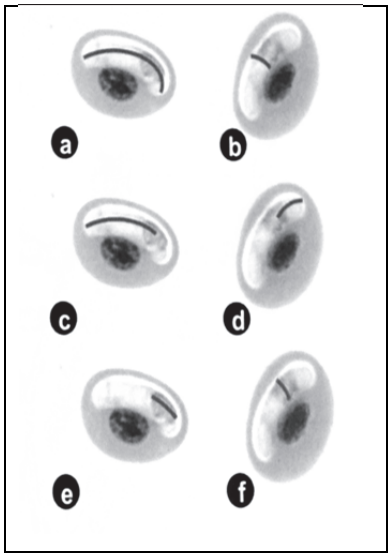


Figure 7.17. Haemogregarinidae morphological measurements (modified from Cook, 2012), used for the morphological description. Body length (BL) (a); body width (BW) (b); mid nucleus to anterior end (MA) (c); mid nucleus to posterior end (MP) (d); nucleus length (NL) (e); nucleus width (NW) (f).

Immature gamonts: oval-shaped without gap or cavity at anterior pole (Figure 7.18 D-F); capsule measured 14.15 ± 0.68 µm (11.59-15.96) long, by 7.51 ± 0.51 µm (6.01-8.49) wide (n = 133). Whitish-blue-purple stained cytoplasm sometimes with pink-purple stained granules; irregularly oval-shaped, blue or purple stained nucleus measured 5.03 ± 1.35 µm (3.34-7.28) long, by 3.93 ± 0.80 µm (1.86-6.08) wide, lying nearer to the posterior pole; in some cases the gamont would cause the nucleus to split (Figure 7.18) (Cook et al., 2009).

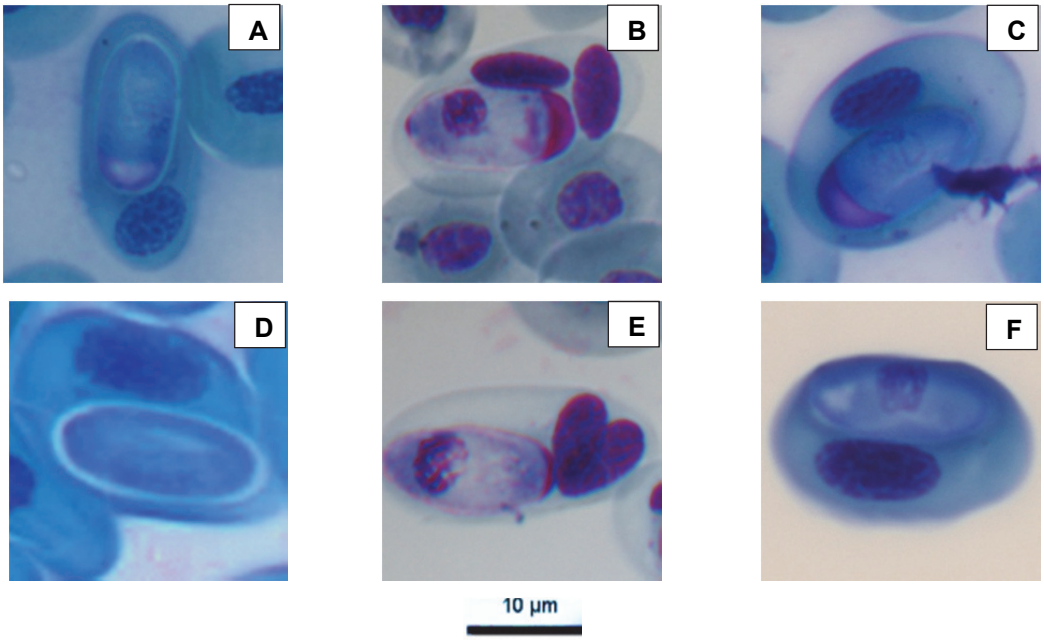


Figure 7.18. Giemsa-stained blood films of *A. garmani, A. gutturalis, and A. maculatus* with species A (A-F). Mature gamonts (A-C) and immature gamonts (D-F). Present blood parasites causing nucleus to split in both (B) and (E).

7.3.4 Birds

In Table 7.13 a list is given of all bird species observed during the April, July, September and November 2013 field trips.

Table 7.13. Complete list of bird species recorded at various sites during 2013-2014 with numbers of individuals given.

Bird species list (156 species, 6 419 counts)							
Scientific name	**Common name**	**Total**	**O**	**P**	**B**	**C**	**N**
Accipitridae							
Accipiter melanoleucus	Black sparrowhawk	2	X		X		
Accipiter tachiro	African goshawk	2	X			X	
Haliaeetus vocifer	Fish eagle	31	X		X	X	X
Milvus migrans	Black kite	4				X	
Polyboroides typus	African harrier-hawk	1					X
Alcedinidae							
Alcedo cristata	Malachite kingfisher	5	X		X	X	
Anatidae							
Alopochen aegyptiaca	Egyptian goose	130	X	X	X	X	X
Plectropterus gambensis	Spur-winged goose	95		X	X	X	X

Table 7.13. (continued)

Anhingidae							
Anhinga rufa	African darter	6	X		X		
Apodidae							
Apus affinis	Little swift	50				X	
Cypsiurus parvus	African palm swift	1				X	
Ardeidae							
Ardea cinerea	Grey heron	18			X	X	X
Ardea goliath	Goliath heron	2				X	
Ardea melanocephala	Black-headed heron	5				X	X
Ardea purpurea	Purple heron	2				X	
Ardeola ralloides	Squacco heron	5				X	
Bubulcus ibis	Cattle egret	62	X	X	X	X	X
Butorides striata	Green-backed heron	27	X	X	X	X	X
Egretta alba	Great white egret	11			X	X	X
Egretta garzetta	Little egret	26			X	X	
Bucerotidae							
Bycanistes bucinator	Trumpeter hornbill	141	X	X	X	X	X
Tockus alboterminatus	Crowned hornbill	49	X	X	X	X	X
Burhinidae							
Burhinus vermiculatus	Water dikkop	11				X	X
Campephagidae							
Campephaga flava	Black cuckoo shrike	1		X			
Caprimulgidae							
Caprimulgus pectoralis	Fiery-necked nightjar	1				X	
Centropodidae							
Centropus burchellii	Burchell's coucal	12	X			X	X
Cerylidae							
Ceryle rudis	Pied kingfisher	45	X	X	X	X	X
Megaceryle maximus	Giant kingfisher	29	X	X	X	X	X
Charadriidae							
Charadrius tricollaris	Three-banded plover	48				X	X
Vanellus armatus	Blacksmith lapwing	2				X	
Ciconiidae							
Ciconia episcopus	Woolly-necked stork	1				X	
Leptoptilos crumeniferus	Marabou stork	1				X	
Mycteria ibis	Yellow-billed stork	30			X	X	X
Cisticolidae							
Apalis flavida	Yellow-breasted apalis	104	X	X	X	X	X
Apalis ruddi	Rudd's apalis	7					X
Camaroptera brachyuran	Green-backed camaroptera	126	X	X	X	X	X
Cisticola chiniana	Rattling cisticola	3				X	X
Cisticola erythrops	Red-faced cisticola	1	X				
Prinia subflava	Tawny-flanked prinia	66	X	X	X	X	X
Coliidae							
Urocolius indicus	Red-faced mousebird	36	X				X

Table 7.13. (continued)

Columbidae							
Streptopelia capicola	Cape turtle dove	1	X				
Streptopelia semitorquata	Red-eyed dove	144	X	X	X	X	X
Streptopelia senegalensis	Laughing dove	1					X
Treron calvus	African green pigeon	41	X		X	X	X
Turtur chalcospilos	Emerald-spotted wood dove	117	X	X	X	X	X
Turtur tympanistria	Tambourine dove	14	X	X	X	X	
Coraciidae							
Eurystomus glaucurus	Broad-billed roller	3		X	X		
Cuculidae							
Chrysococcyx caprius	Diederik cuckoo	2				X	
Cuculus solitaries	Red-chested cuckoo	7		X	X		X
Dacelonidae							
Halcyon albiventris	Brown-hooded kingfisher	70	X	X	X	X	X
Halcyon chelicuti	Striped kingfisher	3	X		X		X
Halcyon senegalensis	Woodland kingfisher	3		X		X	
Dendrocygnidae							
Dendrocygna viduata	White-faced duck	212	X	X	X	X	X
Dicruridae							
Dicrurus adsimilis	Fork-tailed drongo	58	X	X	X	X	X
Dicrurus ludwigii	Square-tailed drongo	206	X	X	X	X	X
Estrildidae							
Lagonosticta senegala	Red-billed firefinch	7					X
Mandingoa nitidula	Green-backed twinspot	1		X			
Uraeginthus angolensis	Blue waxbill	14					X
Eurylaimidae							
Smithornis capensis	African broadbill	7	X	X	X		X
Fringillidae							
Crithagra mozambicus	Yellow-fronted canary	23			X	X	X
Emberiza flaviventris	Golden-breasted bunting	6				X	X
Heliornithidae							
Podica senegalensis	African finfoot	3	X		X		
Hirundinidae							
Hirundo rustica	Barn swallow	100		X			X
Hirundo smithii	Wire-tailed swallow	94	X		X	X	X
Hirundo abyssinica	Lesser striped swallow	350	X	X	X	X	X
Psalidoprocne holomelaena	Black saw-wing	36	X	X	X	X	
Indicatoridae							
Indicator variegatus	Scaly-throated honeyguide	1	X				
Lybiidae							
Pogoniulus bilineatus	Yellow-rumped tinkerbird	40	X	X	X	X	X
Pogoniulus pusillus	Red-fronted tinkerbird	29	X	X	X	X	X
Stactolaema leucotis	White-eared barbet	158	X	X	X	X	X

Table 7.13. (continued)

Malaconotidae							
Batis molitor	Chinspot batis	29	X		X	X	X
Dryoscopus cubla	Black-backed puffback	60	X	X	X	X	X
Laniarius ferrugineus	Southern boubou	23					X
Malaconotus blanchoti	Grey-headed bush shrike	2					X
Prionops plumatus	White-crested helmet shrike	57		X	X	X	X
Prionops retzii	Retz's helmet shrike	4					X
Tchagra australis	Brown-crowned tchagra	7	X		X		X
Telophorus sulfureopectus	Orange-breasted bush shrike	9		X		X	X
Telophorus viridis	Gorgeous bush shrike	19				X	X
Meropidae							
Merops apiaster	European bee-eater	1					X
Merops persicus	Blue-cheeked bee-eater	134	X	X	X	X	X
Merops pusillus	Little bee-eater	15			X	X	X
Monarchidae							
Terpsiphone viridis	Paradise flycatcher	45	X	X	X	X	X
Trochocercus cyanomelas	African crested flycatcher	53	X	X	X	X	X
Motacillidae							
Anthus cinnamomeus	African pipit	8					X
Motacilla aguimp	African pied wagtail	9			X	X	X
Muscicapidae							
Bradornis pallidus	Pale flycatcher	8				X	
Cercotrichas leucophrys	White-browed scrub-robin	11	X	X	X		X
Cercotrichas quadrivirgata	Bearded scrub robin	1					X
Cossypha heuglini	White-browed robin-chat	27	X	X	X	X	X
Cossypha humeralis	White-throated robin-chat	1					X
Cossypha natalensis	Red-capped robin-chat	161	X	X	X	X	X
Ficedula albicollis	Collared flycatcher	1	X				
Melaenornis pammelaina	Southern black flycatcher	11			X	X	X
Muscicapa adusta	African dusky flycatcher	11			X		
Muscicapa caerulescens	Ashy-breasted flycatcher	27	X	X	X	X	X
Myioparus plumbeus	Grey tit-flycatcher	24	X	X		X	X
Musophagidae							
Gallirex porphyreolophus	Purple-crested turaco	80	X	X	X	X	X
Nectariniidae							
	Sunbird (general)	101	X	X	X	X	X
Chalcomitra senegalensis	Scarlet-chested sunbird	16		X	X	X	
Cinnyris bifasciatus	Purple Banded Sunbird	50	X	X	X	X	X
Cinnyris talatala	White-bellied sunbird	15		X	X	X	X
Cinnyris venustus	Yellow-bellied sunbird	1			X		
Cyanomitra olivacea	Olive sunbird	1	X				
Cyanomitra veroxii	Grey sunbird	115	X	X	X	X	X
Hedydipna collaris	Collared sunbird	46	X	X	X	X	X
Numididae							
Guttera edouardi	Crested guineafowl	128	X	X	X		X
Numida meleagris	Helmeted guineafowl	72	X		X	X	

Table 7.13. (continued)

Oriolidae							
Oriolus larvatus	Eastern black-headed oriole	10	X	X	X		
Paridae							
Anthoscopus caroli	Penduline tit	5					X
Parus niger	Southern black tit	44		X	X	X	X
Pelecanidae							
Pelecanus rufescens	Pink-backed pelican	26			X	X	X
Phalacrocoracidae							
Phalacrocorax africanus	Reed cormorant	6			X	X	
Phalacrocorax lucidus	White-breasted cormorant	5				X	
Phasianidae							
Dendroperdix sephaena	Crested francolin	10	X			X	X
Francolinus natalensis	Natal francolin	9	X				X
Phoeniculidae							
Phoeniculus purpureus	Green wood hoopoe	72	X	X	X	X	X
Picidae							
Campethera abingoni	Golden-tailed woodpecker	61	X	X	X	X	X
Dendropicos fuscescens	Cardinal woodpecker	5		X	X		
Dendropicos namaquus	Bearded woodpecker	1					X
Ploceidae							
Ploceus bicolor	Dark-backed forest weaver	110	X	X	X	X	X
Ploceus cucullatus	Village weaver	5				X	X
Ploceus intermedius	Lesser masked weaver	9		X		X	X
Ploceus ocularis	Spectacled weaver	2				X	
Quelea quelea	Red-billed quelea	20					X
Pycnonotidae							
Andropadus importunus	Sombre greenbul	154	X	X	X	X	X
Chlorocichla flaviventris	Yellow-bellied greenbul	21	X		X		X
Nicator gularis	Eastern nicator	25		X	X	X	X
Phyllastrephus terrestris	Terrestrial brownbul	83	X	X	X	X	X
Pycnonotus tricolor	Dark-capped bulbul	625	X	X	X	X	X
Rallidae							
Ardea melanocephala	Black crake	1				X	
Recurvirostridae							
Himantopus himantopus	Black-winged stilt	3					X
Rhinopomastidae							
Rhinopomastus cyanomelas	Scimitarbill	4			X		X
Scolopacidae							
Actitis hypoleucos	Common sandpiper	5				X	X
Tringa glareola	Wood sandpiper	7					X
Tringa nebularia	Common greenshank	4					X
Scopidae							
Scopus umbretta	Hamerkop	13	X		X	X	

Table 7.13. (continued)

Strigidae							
Bubo lacteus	Verreaux's eagle owl	18	X			X	
Scotopelia peli	Pel's fishing owl	2	X	X			
Strix woodfordii	Wood owl	1		X			
Sturnidae							
Buphagus africanus	Yellow-billed oxpecker	6					X
Cinnyricinclus leucogaster	Violet-backed starling	10		X	X	X	X
Lamprotornis nitens	Cape glossy starling	80					X
Lamprotornis corruscus	Black-bellied starling	39	X			X	
Sylviidae							
Bradypterus baboecala	Little rush-warbler	12				X	
Chloropeta natalensis	Dark-capped yellow warbler	1			X		
Sylvietta rufescens	Long-billed crombec	1					X
Turdoides jardineii	Arrow-marked babbler	17					
Threskiornithidae							
Bostrychia hagedash	Hadeda ibis	292	X	X	X	X	X
Platalea alba	African spoonbill	29				X	X
Plegadis falcinellus	Glossy ibis	2			X	X	
Threskiornis aethiopicus	Sacred ibis	12			X	X	
Trogonidae							
Apaloderma narina	Narina trogon	4	X	X		X	
Upupidae							
Upupa africana	African hoopoe	11			X	X	
Zosteropidae							
Zosterops senegalensis	African yellow white-eye	199	X	X	X	X	
Zosterops virens	Cape white-eye	4	X		X	X	
Total count		**6419**					

Every species counted in each plot of each site has been added to this list, as well as the number of individuals of each species observed throughout the survey period. In total 161 species were noted, for 12 880 records (4 surveys x 5 sites x 4 plots x 161 species), with 6 419 birds counted. Some of the species were abundant and others were only seen once. Some of the most abundant species were: barn swallow (100), blue-cheeked bee-eater (134), crested guineafowl (128), dark-backed forest weaver (110), dark-capped bulbul (625 – most abundant), Egyptian goose (130), emerald-spotted wood dove (117), green-backed camaroptera (126), grey sunbird (115), hadeda (292), lesser striped swallow (350), white-eared barbet (158), white-faced duck (212), yellow-breasted apalis (104) and yellow white-eye (199).

Data analyses

The species-area curve (Figure 7.19) shows the relationship between the number of species and the number of plots used. At 20 subplots this curve flattens out, meaning that more plots would not have added many more species using the survey techniques employed. This ordination was done using Sørensen (Bray-Curtis) and species with three or fewer individuals were not included as these species contribute little ecological information.

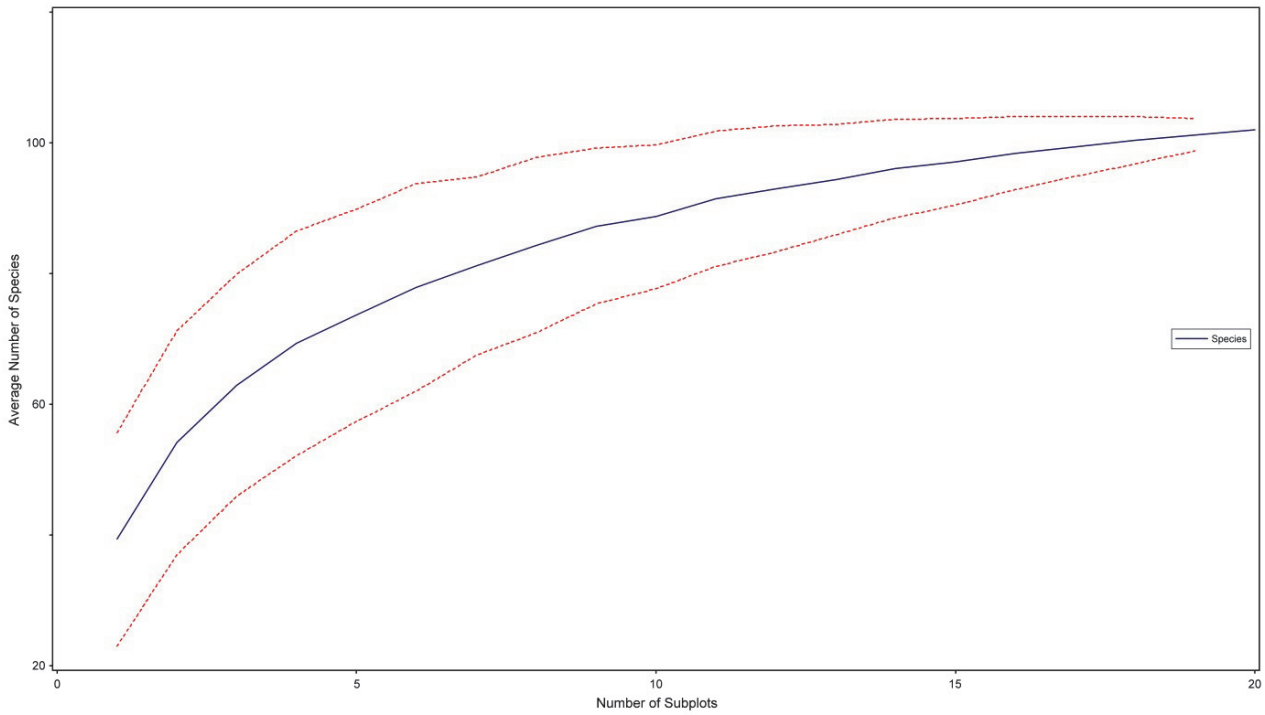


Figure 7.19. Species-area curve for birds at the sub-plots of Ndumo Game Reserve.

For this ordination (Fig. 7.20), PCA was selected as the best model as the dataset (all birds seen at each site) was not amenable to NMDS ordination, using the Bray-Curtis calculation for distance. Axis 1 explained 88.8% of the variation, and Axis 2, 1.9%, for a cumulative explanation of 90.7%. As can be seen in Figure 7.9, Sites 39 and 37 lay quite close to each other, with Site 38 to the far right on axis 1, Nyamithi on the far left and Site 40 on the opposite side of the two furthest sites. Site 39 and Site 37 are near the ordination origin. The following species occurred near the ordination origin: tambourine dove, hadeda, African crested flycatcher, paradise flycatcher, green-backed camaroptera, yellow-rumped tinkerbird, green wood hoopoe, fork-tailed drongo, and helmeted guineafowl, indicating a suite of general species. The blue waxbill, yellow-billed oxpecker, African pipit, crested francolin, eastern nicator and orange-breasted bush shrike were all clustered around Nyamithi. The scarlet-chested sunbird, blue-cheeked bee-eater, trumpeter hornbill and square-tailed drongo were strongly associated with Site 38. Four species were strongly associated with Site 40: arrow-marked babbler, yellow-billed kite, little swift and the little rush-warbler.

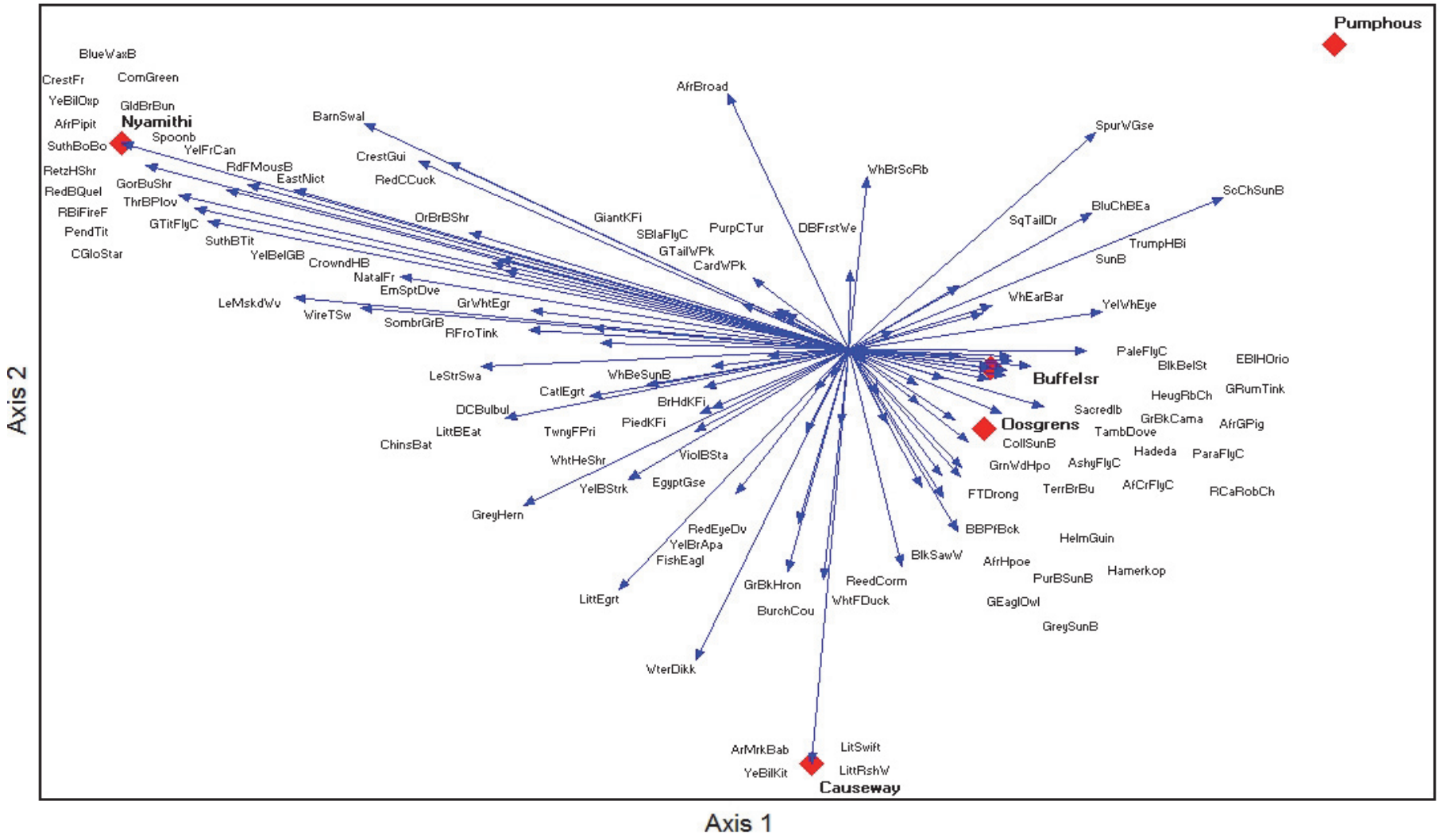


Figure 7.20. PCA ordination of bird species composition in terms of survey sites.

Figure 7.21 is an NMDS ordination with convex hulls per observation-site for each site. The five sites in this ordination show little to no overlap. Site 37 had a little overlap with Site 39, and no overlap with any other site. Site 39 also did not overlap with any site other than a little bit with Site 37. Site 40 overlapped slightly with Site 41, but is far removed from Site 38 and also did not overlap with any other site. Site 41 is on the opposite side of the ordination from Site 38 and only overlaps with Site 40. The transition from the pan site (Site 41) to the site with the highest trees and least shrubs (Site 38) is striking.

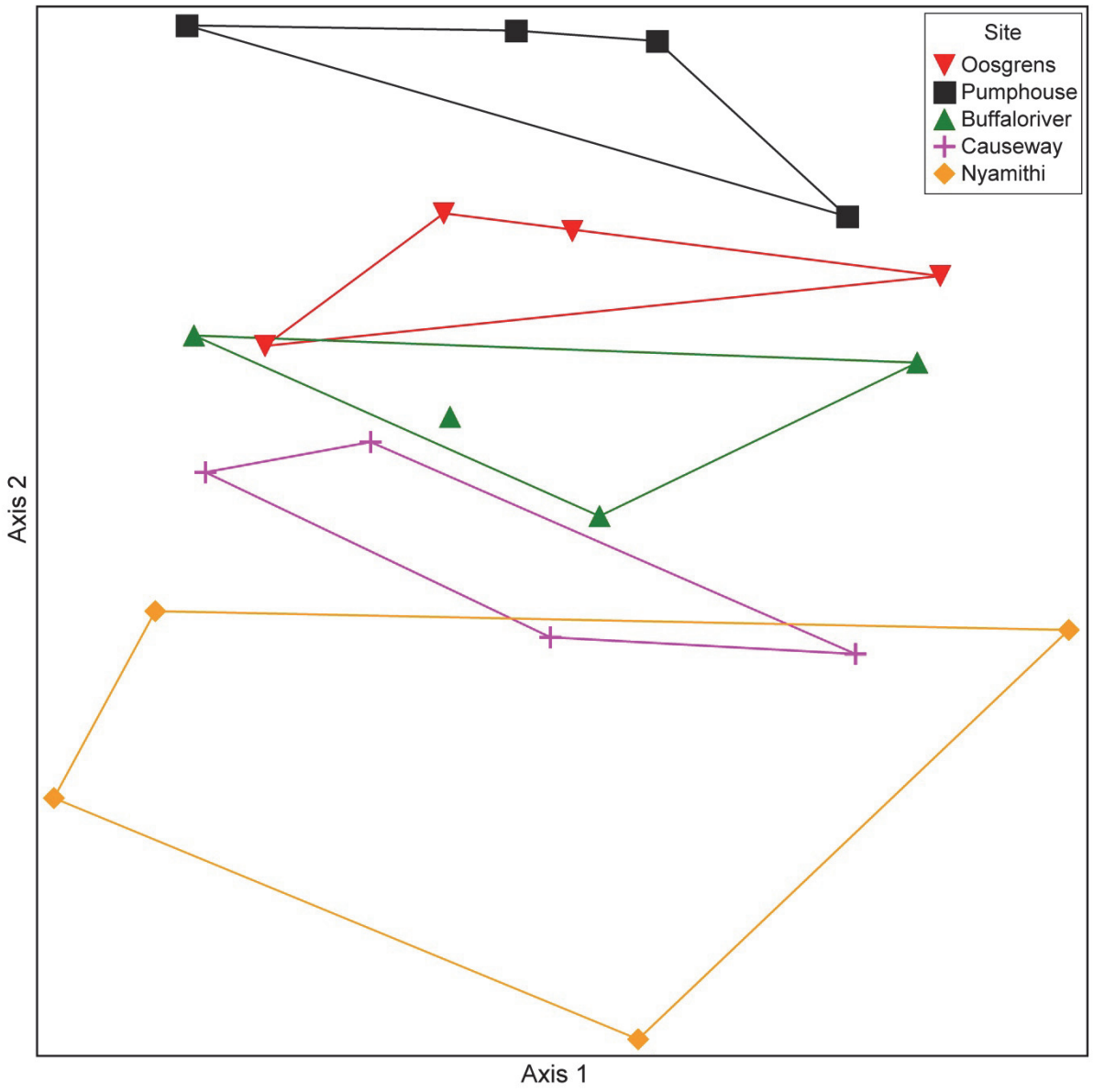


Figure 7.21. NMDS with convex hulls (five sites).

Figure 7.22 presents an NMDS ordination with convex hulls per site (as for Fig. 7.21) with the bird species plotted, as well as the months the surveys were conducted in.

The crested francolin, common greenshank, and red-billed quelea were strongly associated with Site 41, especially during November. During July, the golden-breasted bunting, Cape glossy starling and yellow-billed oxpecker were strongly associated with Site 41.

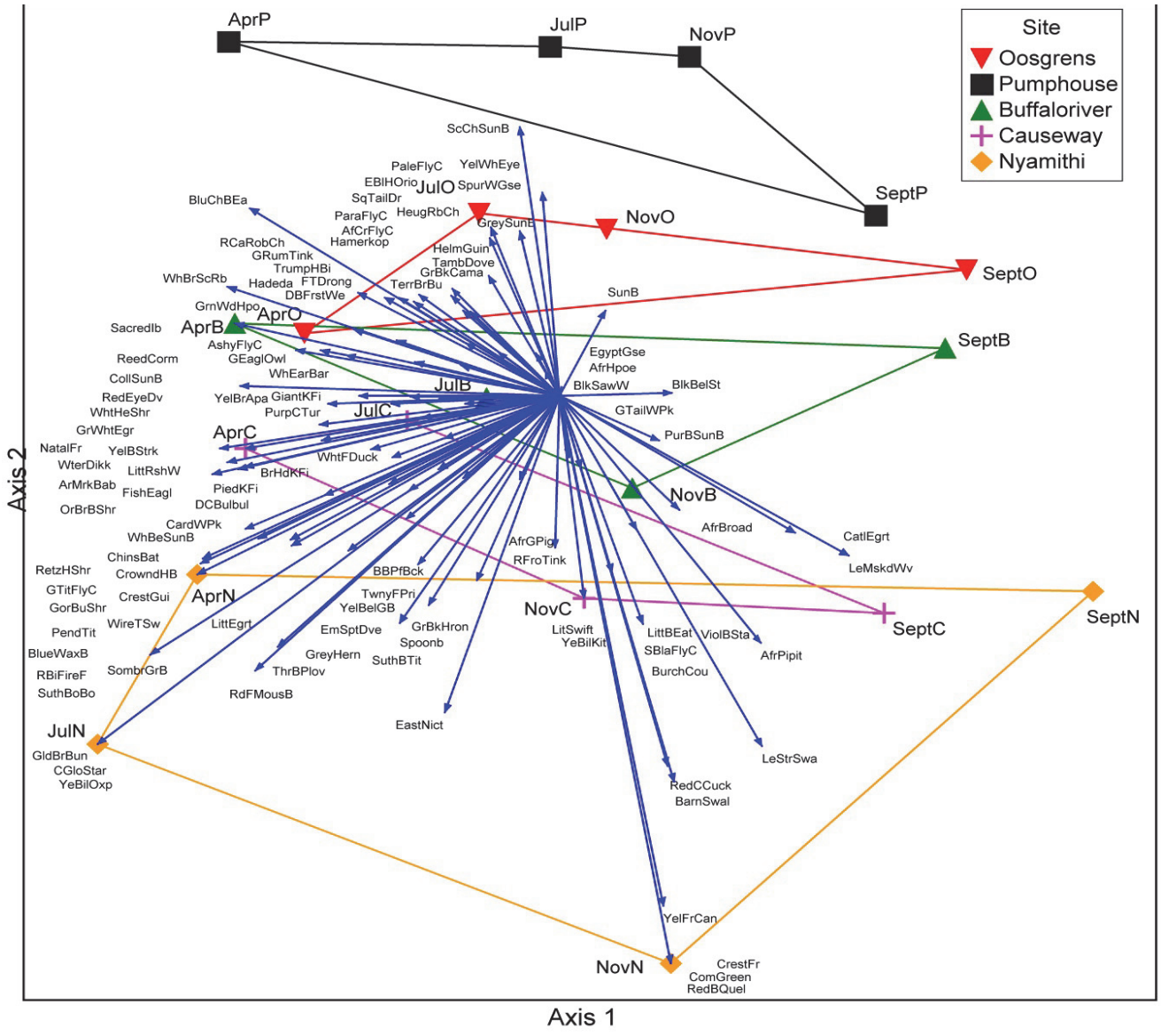


Figure 7.22. NMDS with convex hulls (five sites plus species).

Black saw-wing, African hoopoe, Egyptian goose, black-bellied starling, purple-banded sunbird and golden-tailed woodpecker were all very close to the ordination origin, with scarlet-chested sunbird, yellow white-eye, spur-winged goose, grey sunbird and pale flycatcher associated with Site 38.

The brown-hooded kingfisher, pied kingfisher, fish eagle, orange-breasted bush shrike, little rush warbler, arrow-marked babbler, water dikkop and Natal francolin were associated with the Site 40 in April. Sacred ibis, green wood hoopoe, reed cormorant and ashy-breasted flycatcher were observed at Site 39 during April.

Table 7.14 depicts the results for the indicator species for every site. P-values below 0.1 were considered good indicators. The white-browed robin-chat was a very strong indicator for Site 37, the green-backed heron was a good indicator for Site 40, and the southern black tit an extremely strong indicator for Site 41. No significant indicators were found for Site 38 or Site 39.

Table 7.14. Indicator species (birds) for sites.

Species	Site	Indicator value (IV)	P-value (p*)
African crested flycatcher	37	42.6	0.0742
Helmeted guineafowl	37	55.2	0.0378
White-browed robin-chat	37	48.1	0.0110
Little egret	40	54	0.0920
Green-backed heron	40	50	0.0424
White-faced duck	40	60.5	0.0436
Eastern nicator	41	60.9	0.0288
Sombre greenbul	41	49.7	0.0278
Southern black tit	41	65.9	0.0020
Three-banded plover	41	67.1	0.0208

In Table 7.15 the Shannon diversity index is used to classify sites as most or least diverse in terms of species richness. Site 38 had the smallest value and Site 41 the largest. Species with three or fewer individuals were not included in the equation, resulting in 40 species not being included in this analysis.

Table 7.15. Shannon diversity index of all five sites.

Sites	Shannon diversity index
37	1.996
38	1.980
39	2.164
40	2.237
41	2.044

The following ordination (Figure 7.23) investigated changes in species composition in ordination space. This Bray-Curtis ordination with successional vectors of the five sites uses untransformed data. Sites 37, 38, 39 and 40 all start out to the right of the ordination in April, moving to the left (in the dimension of axis 1) in July and down in the direction of axis 2 in September. In November, the species composition of all three moved upwards in the plane of axis 2. Site 41, on the other hand, showed a different dynamic, origin, and direction of change. The major movement was in the dimension of axis 2, with a major shift in composition between June and September.

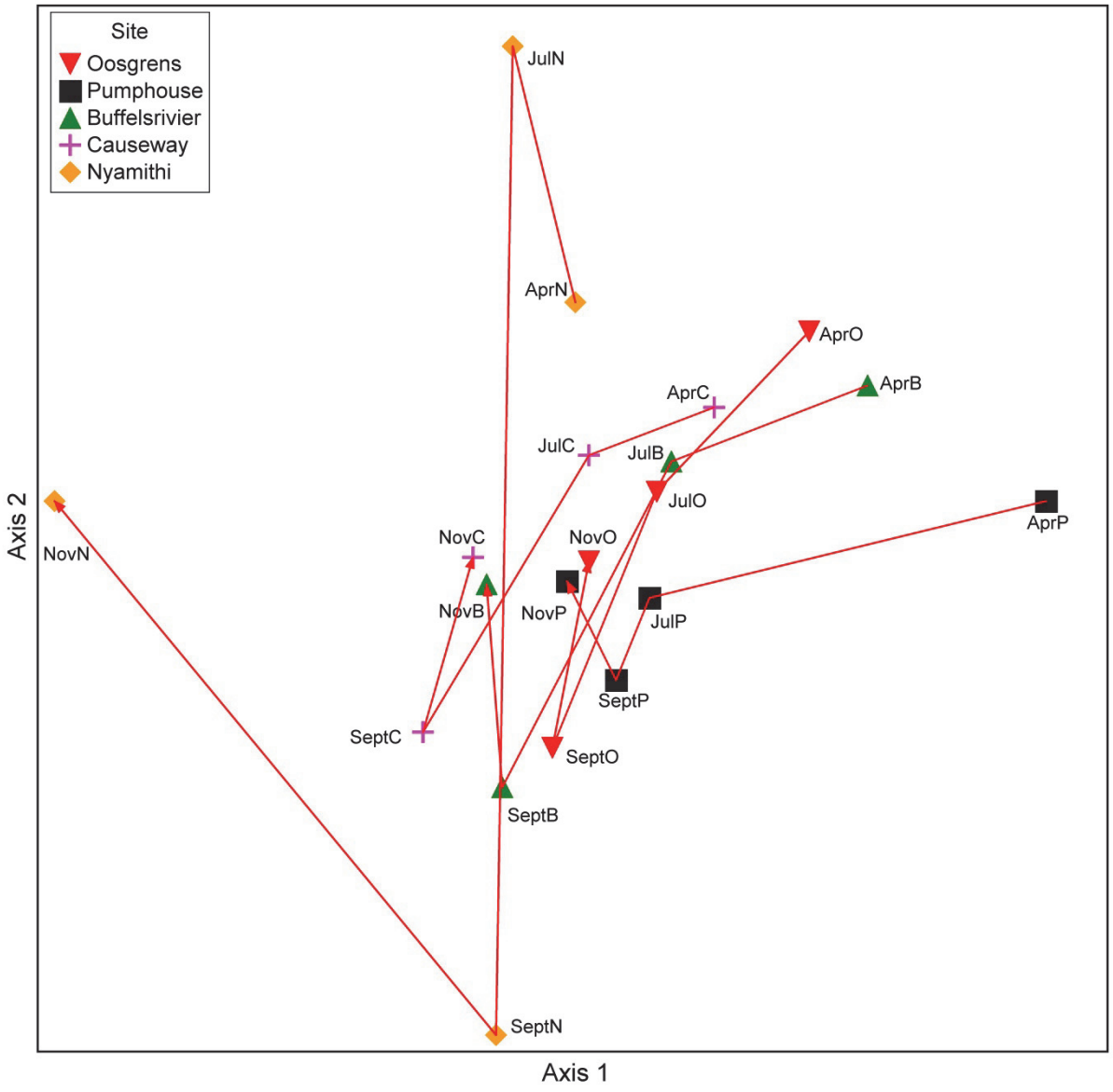


Figure 7.23. Bray-Curtis ordination with successional vectors (five sites).

Figure 7.24 presents the change over time (using Bray-Curtis) and the species added. The species vectors were not included as they obscured many of the species names, but are located between Site 40 and Site 39 in July. It can be seen that the yellow-billed oxpecker, Cape glossy starling and golden-breasted bunting occurred only at Site 41 and then only in July. A congregation of species can be seen near the origin, with the black saw-wing, white-browed robin-chat, green-backed heron, black-backed puffback, giant kingfisher, African crested flycatcher, tawny-flanked prinia and tambourine dove.

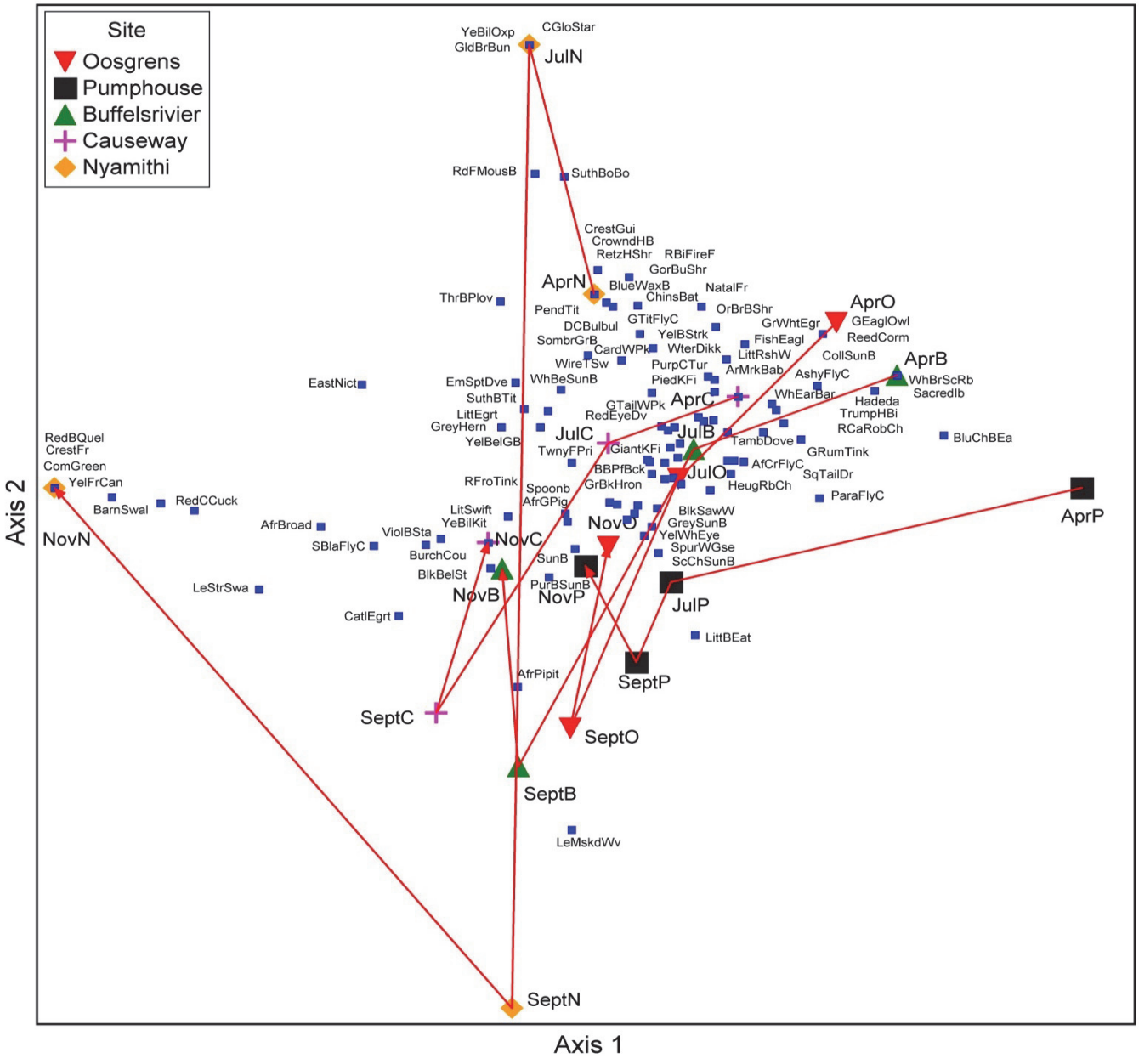


Figure 7.24. Bray-Curtis ordination with successional vectors (five sites plus bird species).

General observations

During the four surveys, 6 378 birds of 161 species were noted. Some of the species are migratory, such as the diederik cuckoo, woodland kingfisher, red-chested cuckoo, barn swallow, lesser striped swallow, yellow-billed kite, common sandpiper, wood sandpiper, European bee-eater, blue-cheeked bee-eater and violet-backed starling.

Depending on the seasons, different species were spotted. Most species were observed during April, possibly because of it being late summer and most migrants were still present. The greatest number of individuals was also counted then, probably due to the breeding season being over and fledglings leaving their nests.

The species with most individuals were mostly those that occur in flocks or family groups, such as the barn swallow, blue-cheeked bee-eater, crested guineafowl, hadeda, lesser striped swallow, white-eared barbet, white-faced duck and yellow white-eye. However, large numbers were recorded of some species that did not occur in flocks, such as: dark-backed forest weaver, dark-capped bulbul, emerald spotted dove, green-backed camaroptera, and yellow-breasted apalis. These species adapt well to different habitat types and thus that may have been the reason why they were present in notable numbers.

Species-area curve

The species-area curve (Figure 7.19) flattens out at 20 subplots. This points to enough plots used for the surveys. The curve does not flatten out completely due to the fact that species with three or fewer individuals were not included in the calculation. If those individuals had been taken into account, the curve would have flattened out completely, thus confirming that 20 sub-plots are sufficient and that enough surveys have been done to give a good indication of the species-area relationship.

<u>Species and site association</u>

Figure 7.20 depicts the species-site relationships. The species compositions of Site 37 and Site 39 were much the same and located close to the ordination origin. This means that these two sites shared many of the commonly occurring species. Site 37 has bushy vegetation, with tall trees and quite a bit of shrubbery. Site 39 had fewer trees than Site 37 (but as tall), and more grass. Site 39 had more shrubs and a patch of reeds. However, these two sites had a similar species composition. Birds such as the yellow-rumped tinkerbird, tambourine dove, African green pigeon, black-bellied starling, and eastern black-headed

oriole were species common to both sites, although they were also present at others in lesser numbers.

Site 38 is located to the right of the ordination. The difference can be explained by a vegetation structure different from the other sites. It has many tall trees and almost no grass, with quite a few shrubs. Birds commonly found at this site were the spur-winged goose, scarlet-chested sunbird, trumpeter hornbill and square-tailed drongo, amongst others. These species are generally associated with tall trees, dense shrubs, and a closed canopy.

Site 41, on the other hand, is grassland mixed with bushveld and open riverbeds. Grass is the dominant vegetation type and trees are few and far between. The species composition of this site is therefore also different from that of the other sites. However, some of the more common species were still observed at this site, such as the dark-capped bulbul, cattle egret, giant kingfisher, red-eyed dove and emerald-spotted wood dove. Species that were strongly associated with Site 41 are the common greenshank, red-billed quelea, yellow-billed oxpecker, blue waxbill, red-faced mousebird, gorgeous bush shrike, eastern nicator and golden-breasted bunting. These species prefer more open spaces, with bushveld type vegetation, shrubs and grass and medium-sized trees. The three-banded plover and African pipit prefer still-standing water and were seen on the muddy river banks, next to the open grass plain.

Site 40 had yet another species profile. Arrow-marked babbler, yellow-billed kite, little swift and little rush-warbler are strongly associated with this site. With reed beds, medium-sized trees and quite a bit of grass, this site is a mixture of the other four. Some general species were red-eyed dove, Egyptian goose, black-backed puffback, yellow-breasted apalis, and green-backed heron. The African broadbill was observed at both Site 38 and Site 41, but nowhere else, hence the strong vector towards the middle of those sites. Water dikkop were observed at Site 40 and Site 41, with more individuals observed at Site 40, hence the slight gravitation towards Site 40.

Species composition per site

Figure 7.21 is an NMDS ordination with convex hulls per site according to the different surveys. On closer inspection of each of the sites, little to no overlap of the convex hulls can be seen. The convex hull shapes were generally the same, but the convex hull for Site 41 was much larger compared with the other sites, which were riverine sites. There was little

overlap among the sites, indicating a unique species and abundance profile for each site. These differences are due to the habitats that have already been described.

The implication of this finding is that within a very small space (3 km radius) there exists a large heterogeneity of habitat forms, each with a characteristic species composition and abundance patterns. This finding must be considered by decision-makers in the planning of future conservation efforts. Although Site 37 already had noticeable anthropogenic impacts close to one shore, the impacts did not yet translate into a noticeable influence on the bird community structure as calculated and presented here. Although no pre-impact data on bird composition of Site 37 are available, it may be that larger birds have been displaced by smaller birds.

By adding the bird species to the NMDS ordination with convex hulls per plot, as well as the months during which the surveys were conducted (Figure 7.22), it becomes clear that every site has a unique species and abundance pattern, most likely due to habitat heterogeneity as discussed above.

No bird species unique to Site 38 were observed. However, its unique composition may be due to species that were not present. Grassland species were absent, as were some of the waders and bush shrikes. The birds that preferred tall trees were present at Site 38, but they were also found at Site 37, which also had tall trees.

Sites 37 and 40 are close to the origin of the graph, thus being more similar in species composition than the rest, yet still uniquely different (Figure 7.22). The species that contributed towards the overlap between Site 37 and Site 39 were (amongst others) the green wood hoopoe, white-browed scrub-robin, dark-backed forest weaver and ashy-breasted flycatcher. These species prefer medium to tall trees with shrubbery, and some open space. However, there is little open space at Site 37, probably explaining the little overlap, once again pointing to high heterogeneity and unique species composition.

Site 39 did not overlap with Site 40, but Site 40 overlapped with Site 41 (Figure 7.22). The species responsible for the overlap are the little bee-eater, southern black flycatcher, violet-backed starling, Burchell's coucal and African pipit. Little bee-eaters nest in river banks and feed over open areas, both of which were present at both sites. African pipits prefer open grassland, also found at both sites. These species explain the reason why the two sites overlap; however, Site 41 had strong associations with crested guineafowl, common greenshank and red-billed quelea. Common greenshank and red-billed quelea were only

observed at Site 41, and crested francolin was observed at Sites 38 and 41, but with larger numbers at Site 41.

Again, differences in habitat structure and vegetation seem to explain the uniqueness of species and abundance patterns observed.

Indicator species

Table 7.14 depicts the indicator species for every site. As previously mentioned, the white-browed robin-chat is a very strong indicator for Site 37. This site has thick riverine bush and very tall trees. This species was also found at two other sites but in very low numbers, thus being a good indicator for Site 37.

The green-backed heron was a good indicator for Site 40. The shallow water and muddy river banks with thick, low hanging branches are an excellent habitat for this species. Once again, it was found at other sites but in much lower numbers. The green-backed heron is thus a good indicator for Site 40.

The southern black tit is a very strong indicator for Site 41, with a $p = 0.002$. High numbers of this species were observed at this site and thus an excellent indicator, while it occurred only in low numbers at other sites. However, it is not clear why this typically bushveld species was identified as an indicator species for a pan-dominated site.

No species with indicator values (p-values below 0.1) were calculated for either Sites 38 or 39.

Species diversity

In Table 7.15, the Shannon diversity index was used to classify sites as most or least diverse in terms of species richness. Site 38 had the lowest species diversity, possibly due to low habitat heterogeneity within the site – mostly tall trees and shrubs, no grass and no open spaces. Site 41 has the highest diversity value, probably due to high habitat heterogeneity, ranging from grassland to bushveld with tallish thorn trees and some muddy river banks. Even though Site 38 has the lowest Shannon diversity value and Site 41 the highest, the other three sites were quite similar in terms of species diversity. However, Figures 7.20 and 7.22 show that the species composition differs, and a diversity index is probably not the best measure for comparisons of structurally different sites.

Change over time

Figure 7.23 shows the changes in species composition over time. Sites 37, 38, 39 and 40 all started out on the right (April), moving in the direction of axis 1 to the left (July), and then moved down in the direction of axis 2 (September). Four of the five sites therefore, moved together according to season. These sites had trees and shrubs in common but some had grass or reeds. Although they had different bird species compositions, these compositions reacted very much in the same manner according to changes in season. Site 41, on the other hand, had a very different pattern of change compared with the other four sites. These differences underscore the need to preserve the different habitat types due to spatial and temporal considerations.

A Bray-Curtis ordination with successional vectors for the five sites and bird species in each of those sites is presented in Figure 7.24, with the change in species composition over time evident.

Barn swallow is present at Site 41 during November. It is a migrating species, and the absence of this species during the winter adds to the change in the species composition when it returns in the summer.

Bird species adapt their behaviour due to many reasons, one being breeding. During the breeding season, they behave differently, maybe foraging further from their original habitat. During winter, territorial behaviour might be relaxed and species groups and even multi-species groups can become quite mobile. This could attribute to the change in the position of the site over time on the ordination. From Figure 7.24 it is evident that the species composition changes over time, with each site having species compositions and abundances, probably as a result of various factors such as behavioural changes, migration, and changes in availability of food and shelter.

From Figure 7.24, it can be seen that the yellow-billed oxpecker, Cape glossy starling and golden-breasted bunting were found at Site 41 only in July. The ordination origin is close to Site 40 in July, with a general species distribution around it, including the black saw-wing, white-browed robin-chat, green-backed heron, black-backed puffback, giant kingfisher, African crested flycatcher, tawny-flanked prinia and tambourine dove.

7.4 Concluding remarks

7.4.1 Macroinvertebrates

The main potential risks for macroinvertebrates in the Lower Phongolo River system include wetland habitat degradation and loss, invasive competitors and pollution (Darwall *et al*., 2008; Snovsky & Galil, 2011; Du Preez & Smit, 2013). Especially for localities outside protected areas, the wetlands in the Lower Phongolo River floodplain are generally heavily exploited for water abstraction, domestic use, and agricultural activities. Like freshwater crabs, freshwater crayfish are dominant macroinvertebrates in freshwater habitats, and both of these crustaceans are potential niche competitors. The invasive freshwater crayfish species *C. quadricarinatus* that is already present in the Phongolo system has the potential for a large impact on southern African freshwater ecosystems in general, including negatively affecting freshwater crab populations (De Moor, 2002). Rivers and wetlands are the ultimate receptacles for chemical pollutants from river catchments, which will affect ecosystem diversity at all taxonomic levels. Invertebrate biodiversity of the Phongolo floodplain and its tributaries can therefore be regarded as under increasing pressure from antHropogenic stressors related to pollution, impoundment, habitat destruction and water abstraction, as well as biological stressors related to alien invasive species.

7.4.2 Fish biodiversity

One of the concerns related to the threat posed by changes to natural flood regime of floodplains is the loss of fish biodiversity. Great variation in the flood regime has occurred in the Lower Phongolo River system between 1986 and 2004. From 2005 it was decided that the flood regime should be standardised and for the past 10 years floods were released during spring which differs from the natural high-flow season which occurs mainly during the summer months. Several species that are dependent on high flow during the summer months in order to breed are now left with very little, if any, habitat and often seek refuge in pans that eventually dry up. After more than 40 years of being dammed it is therefore realistic to fear that some species would have been lost in the Lower Phongolo River and floodplain. This seems to be the case as during the present study only 37 of the 43 known species from this area were collected. At least one of these six species, *Labeobarbus marequensis*, seems to be locally extinct as it was last collected before the severe drought of 1983. Although, fortunately, there has been no significant loss in biodiversity to date, definite changes were noticed in community structures when historical data were compared to recent data. The concern is thus that the change in the community structure as described in the result section might put more native species at further risk of extinction. For example, *M.*

brevianalis, one of the six species not collected during the present study, prefers well-aerated open flowing water and breeds in early summer. It is thus possible that the flow alterations and the early spring flood releases of recent years have caused this species to be replaced by faster colonising species or the lack of habitat during the summer months, which prohibits their recruitment. In order to prevent any further changes to community structures and potential loss of more species, the artificial flood release should ideally coincide with the natural flood events or at least be scheduled for the summer months (December to February) rather than the current spring (September to November) flood releases.

In addition to the changing of natural flood releases another threat to the fish biodiversity of the Lower Phongolo River is the presence of invasive species. The invasive common carp, *C. carpio*, was first collected in the Lower Phongolo in 1993 (Merron et al., 1994a). During the present study, large numbers of all different life stages of *C. carpio* were collected from all of the pan sites sampled (Figure 7.25). The negative impact of common carp on indigenous fish is well documented and together with the stress of an unnatural flood regime can contribute to further changes in fish community structures and could potentially bring about the local extinction of ecologically sensitive species.



Figure 7.25. Photos of the alien *C. carpio* caught at various pans within the Ndumo Game Reserve.

7.4.3 Amphibians

The small seasonal well-vegetated pans are the prime breeding sites for a number of anuran species. Frogs have very specific habitat requirements and the diverse habitats in the Ndumo Game Reserve cater for a variety of species. The reserve thus serves as refugia for several species. Frogs are the staple food for many bird species and the value of amphibians as food source for the rich bird diversity should not be underestimated.

The introduction of the alien redclaw crayfish (*Cherax quadricarinatus*) might pose a serious risk to tadpoles. Studies to document the threat that redclaw crayfish might pose should be a high priority as it is of national importance.

Amphibians are extremely sensitive to chemical pollutants in water. Chemical pollution degrades the quality of the streams and rivers feeding into the study area; poor water quality might have a devastating effect on the amphibian diversity in the study area. When the immune system of frogs is compromised, it often results in unusually high parasite loads, which may impact on the frogs' survival.

Potential mediation to protect the amphibian diversity will include:

- Monitoring of the water quality of the different streams and rivers.
- Preventing redclaw crayfish from entering the smaller streams, ponds and pans.
- Educating the local people in the area through posters about the importance of amphibians in the environment and the unique species diversity of the area.

7.4.4 Birds

It is evident that the sites that were surveyed, although located in fairly close proximity to each other, differ from one another in terms of bird species composition, abundance, and changes over time. Sites with higher habitat heterogeneity were observed to have higher bird species diversity. Even the four riverine sites were surprisingly different in species composition and abundance patterns, but had similar changes over time. The site that had some anthropogenic impact (Site 37) showed what might be termed "resilience" to such impacts. Combined, this survey showed that spatial differences and temporal changes play a significant part in the bird biodiversity of Ndumu Game Reserve and by extension thereof, also the rest of the Phongolo floodplain. The message is clear: small-scale habitat heterogeneity needs to be preserved, although a measure of disturbance might be tolerated. In addition, highly conserved areas should form part of the mosaic of a floodplain such as the Phongolo.

7.4.5 In summary

In this study macroinvertebrates, fish, amphibians and birds were selected as focal groups to represent the biodiversity spectrum from invertebrates, lover chordates to higher chordates. The single most important aspect that was identified by each of the four taxonomic groups was the integrity of the Phongolo floodplain and the Ndumo Nature Reserve as a whole. Key corner stones that will determine this integrity of the study area includes the flood regime, sedimentation and habitat heterogeneity.

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8 EXPLORING HUMAN WELLBEING IN THE PHONGOLO RIVER AND FLOODPLAIN, WITH EMPHASIS ON THE USE OF FISH AS AN ECOSYSTEM RESOURCE IN THE NDUMO COMMUNITY

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When the authors undertook the task of broadly assessing human wellbeing, and the socio-economic status, associated with the use of fish as an ecosystem resource in the Phongolo River and floodplain, a few objectives were listed to compliment the broader project focus on sustainable utilization and management of aquatic resources. Among others, the social, cultural and economic life around fishing habits (including perceived experiences regards the Phongolo floodplain management, health, wellbeing status and perhaps tourism opportunities) were regarded as objectives to focus on. Residents' impressions (the impersonations of some *Indunas*, other community leaders and members of community) about the socio-economic value of the fishery (subsistence vs. commercial) for the community, inclusive of the community's interactions, associations and perceptions with the aquatic resources close to the floodplain were considered. Whether any threats from a community perspective on cultural fishing events existed, as well as threats related to fishing habits and associated with the level of fish consumption, became part of the broader project aim related to the use of fish as an ecosystem service in the Phongolo River and floodplain.

The research eventually followed the standard protocol of an integrative literature review, including an extensive literature search among four (not necessarily related) disciplines (namely Sociology, Psychology, History and Zoology. Afterwards close-up fieldwork followed which resulted in three phases of exploring the availability of information at the Jozini Local Municipality and engaging in fieldwork, inclusive of structured interviews with members of communities stretching from Jozini and explicitly, more extensively, covering the Ndumo community further north.

A lack of published research and reports, at the time of writing, on the general wellbeing of communities and particularly their fishing practices in the northern parts (lower parts) of the Phongolo River and floodplain (namely the Ndumo area) as viewed by the community themselves, allowed for an opportunity to fill a historical gap in scientific information. Yet it should be acknowledged that the informative pioneering research by Heeg and Breen in 1982 as well as the recently published all-embracing study by Lankford et al (2010 and 2011) within the Project "The Pongola River ecosystem Services for Poverty Alleviation (PRESPA)" provided in-depth responses on the Phongolo floodplain resources (as well as some fish practises) along the Phongolo floodplain. The findings by Lankford et al (2010) that over-fishing and changes in the timing of floods resulted in a decrease in fish stocks and regular cultural practises like fishing drives were borne in mind in this research effort. Also the 2012-unpublished preliminary report by the African Centre for Water Research (ACWR) on Poverty land and agrarian studies (known as PLAAS) was utilised as another recent source of information that, among others, covers features of indigenous knowledge and practice on fish regards maintenance, commercial and recreational techniques. The research findings, to be discussed in the next sections, were not an effort to re-invent the wheel with respect to the recent findings of Lankford et al (see also the 2011 publication) and that of the ACWR. The research findings of the ACWR still appears to be in progress of being finalised and is awaited to be exposed by all interested. By especially considering these milestone contributions, apart from some other indirect-related literature, the researchers engaged with the aims as agreed on in the project and as discussed earlier, namely a more focussed scope on the Ndumo community's human wellbeing status in the Phongolo River and floodplain, with emphasis on the use of fish as an ecosystem resource.

In the first of the three phases of research some qualitative research was done, covering a broad reconnaissance with various *Indunas* and leaders as well as some elderly from several communities along the Phongolo floodplain, and not only Ndumo. These findings will be discussed in consideration with the second and third phase fieldwork closer to the Ndumo community (as a present-day ward of the Jozini Local Municipality). Its constructive value to the broader project and the necessity to help understand the fishing practices of this self-perceived "forgotten" rural community also created an opportunity for the research team to explore new ways of integrating their expertise to the benefit of the project focus.

A response to the aforementioned research objectives is contained in Sections 8.1 to 8.3 to follow. Section 8.1 provides some context on the first phase qualitative exploration in which some traditional community leaders (*Indunas*) and other community leaders were interviewed, and the questions asked were mostly related to their experience of the

Phongolo floodplain from the perspective of the community they represent or connect with. In Section 8.2 some observations by community members close to the Ndumo community, are made. The observations are about their livelihood, their appreciation of environment and the utilisation of natural sources are explored, while Section 8.3 provides details of a more specific research focus on human-fish interactions in Ndumo.

8.1 Contextualising the beneficiality of the Phongolo River and floodplain and its aquatic resources in the minds of local leadership: a concise qualitative reconnaissance

8.1.1 Introduction

In phase one of the research the point of departure mostly was explorative with the aim to – through constructive interviewing – observe, listen and record a selection of local leaders in the Jozini municipal area's view on the beneficiality of the Phongoloa floodplain. Ten explorative questions were developed for the interviews with local community members (See appendix A).

Fifteen leaders representative from communities in the Jozini local municipal area were selected for interview (fourteen males and one female) between the ages of 47 and 62. These participants were purposively selected (Creswell, 2007), based on their knowledge and experience of their communities' and aspects of interactions with fish. This was the case as all participants were community elders (*Indunas*), who occupy central roles in their respective communities.

The selection of interviewees was made possible by the employees of the Jozini local municipality who identified some people and who also assisted the researchers with the contact details of these people. With the assistance of an experienced fieldworker in research, and well-spoken in IziZulu, some local leaders as identified, were constructively interviewed to inform the researchers, among others, on their views regards the natural resources in the floodplain with emphasis on fish and their impressions of the wellbeing state of the communities they either lead as *Indunas* or represent as a leader.

The 15 interviewees resided in Jozini Town and the following areas in the Jozini local municipal region: Sqakatha; Nyashane; Mjindi farming; Nyawo; Pongola Poort Dam/Ejozini Dam in Othobothini area; the Mngomezulu of Ingwavuma and Shukela. The ten questions formulated for interviewing mainly covered three themes, namely the i) Two questions on the environmental consciousness of the community; ii) Two questions on the wellbeing of the

community in general and iii) Six questions on the community's interactions with the Phongolo floodplain. As the focus of the Project aim within the objectives of Chapter Eight is exploring human wellbeing in the Phongolo River and floodplain, with emphasis on the use of fish as an ecosystem resource in the Ndumo community, the phase one research which was conducted closer to Jozini town, provided for valuable insight on three key themes for progressing to phases two and three of the research**.** The outcome is concisely discussed in Section 8.1.2.

8.1.2 Results from a first phase qualitative exploration

Environmental consciousness of the community

A general understanding of the community in the Jozini local municipality's view about nature was regarded as a way to understand in what sense they see it as mainly related to their economic needs or totally separated from it in an aesthetic sense. The majority of the responses were attached to aspects of economic value such as:…*we love nature because it helps when we are ploughing to generate some food for our children*. Also: … *as people we must learn to appreciate water as a natural resource, because it gives life to plants and animals, and also to human beings*.

From the responses received the environmental value of the Phongolo River and floodplain area for the interviewees also positively featured. To mention some reactions: *People love the environment, they can take care of it….they don't pollute the River… people here respect natural resources… Environment gives us food so we should take care of it, it is very important … People here have an idea about what nature is, and how to take care of our natural resource. We are being educated as leaders, and in return we share the knowledge with them. Though, o*ne interviewee contested the youth's respect for nature: *older generations respect nature, but the younger generations don't know how to respect nature*.

The general wellbeing of community

The questions related to wellbeing were if respondents could provide insight on the most important things that make people in their community happy as well as unhappy? From the responses on being happy or not being happy (and the latter actually "angry" as it was translated to them in IsiZulu), were mostly related to the Phongolo River and Dam. If water was "timely" released from the River people experience happiness with prospects to look forward to an environment which is economically and socially viable for each community and individual. As one interviewee puts it: *People must be able to do their ploughing since there*

are no job opportunities. That's how people survive, by ploughing… they also have livestock. Their cows can graze next to the river, where the grass is much greener because of the water. That people experience some dignity in being *able to generate food for ourselves*, was also noted as a reason for making them happy. Another reflection of happiness by an interviewee was associated with success in the sense of *if there is understanding and co-operation between those who are in charge of the dam and the community*.

Angriness, though perceived as a "*small thing*" by some leaders, were viewed as when water is not being timely released for using. Also flooding, causing deaths of animals drowning as well as *children not to be able to go to school,* was noted as major reason for unhappiness. However, several participants also raised concerns about the water release process. In the words of one participant: 'The way it [is] released … causes damage to the cows because it's not released properly. Sometimes it's in the path where people and school children pass…. These children end up having problems because of the water. The problem referred to here revolves around the concern that children are unable to go to school as pathways to the schools are flooded during times when the water is released'. To remedy this problem some participants suggested the building of small bridges.

Human interactions with the Phongolo floodplain

In the six questions related to this theme the value of the floodplain for cultivation and utilising the natural resource possibilities like fishing, maize/mealies, sugar cane, vegetables and fruit were unanimously echoed. Again the "untimely" flooding was mentioned as not all living close to the floodplain appears to be informed. Also the value and level of fishing in particular were communicated.

Participants indicated that the rainfall in the Phongolo floodplain area was often insufficient for community members to plough and plant crops, and that the controlled release of water '*helps a lot because people can use it in many ways. They are able to plough.*' In addition to agriculture, participants also identified a variety of other uses of the water, which included washing, using water for drinking, to water livestock and for religious rites such as baptism. In the words of a local chief: *They can access drinking water, they can wash*…' and 'the cows can drink and religiously they baptise'.

In times of flooding the destruction of food gardens was mentioned repeatedly by participants as representing a negative outcome of the water release. In the words of one participant: *The problem we have here about water is that when the water is released, and people have ploughed food, their gardens get destroyed, the food becomes rotten.* A few

participants also raised health-related concerns in relation to the seasonal flooding: *The other bad thing is that … we often get illnesses such as fever, diarrhoea and other illnesses*. Overall therefore, it appears that improved mechanisms for controlled flooding plays an important role in supporting local livelihoods by enabling residents to plant subsistence crops, water their livestock, and fish.

As far as it concerns fish as aquatic source participants confirmed that locals do frequently utilize the river and floodplain region for fishing. This practice was mostly in the service of personal subsistence (either for direct consumption, or small scale commercial purposes to support personal livelihoods). Also compare Heeg and Breen (1982). It was further indicated that fishing activity often increases after the controlled release of water from the Pongolapoort dam.

Most respondents complained about the lack of a proper fish industry for all along the Flood Plain, but confirmed that the buying and selling of fish for survival and own use is common: *People go with nets and lanes to catch the fish. Some sell the fish, which they sell in order to earn a living*.. Three leaders added (and in some sense contradicting the others) that: *There is a fish industry, people buy fish, some own fish farms. Some are granted licences to fish, whereas some are not allowed to fish; ... There's a dam which is controlled by nature reserve, people are not allowed to fish when there are floods;… In our area we don't have a place to catch the fish, except for the people who go to the River for fishing. Some people get the permission from the Department of Water Affairs and Environment.*

8.1.3 Discussion

From the general exploration through constructive interviewing in Phase One of the research it became known to the researchers that, despite decades of community awareness regards seasonal flooding and ways of management along the Phongolo River and floodplain, that their living directly and indirectly from this aquatic resource still provokes frustrations because of flooding. Insufficient communication of water releases, and the consequent physical damage to substance farming or/and efforts to fish, appears to be the major constraint in communities' wellbeing. As the Phongolo River and floodplain remains the lifeblood of the rural community life in the Jozini local municipal area for decades to come, the urge for proper risk management in times of flooding has culminated from the interviews. Equally so the suggestion that initiative should be taken towards developing a tailor-made fishing industry on a bigger scale than just a focus on individual self-sufficiency. Most rural

communities along the floodplain are associated with poverty and close to 45 percent rely on government grants (Jozini Local Municipality, 2013-2014).

To obtain a more close-up understanding on one section of the Jozini Local Municipality's managerial area related to specifically the Lower Phongolo River and floodplain and its aquatic resources the Ndumo Community was selected as the area for further research. Sections 8.2 and 8.3 are the outcomes of a more in-depth investigation on the wellbeing of this community as well as to what levels this community utilise the aquatic resources, given the fact that, amongst others, strict regulations and environmental preservation of pans exist in the Ndumo Nature Reserve.

8.2 A reflection on the psycho-social wellbeing of a "forgotten" South African community: The case of Ndumo, KwaZulu-Natal

8.2.1 Introduction

This study investigated the psycho-social wellbeing of the Ndumo community in South Africa (i.e. a ward of the Jozini municipality consisting of five villages on the southern border of Ndumo Game Reserve). A mixed-methods sequential explanatory design procedure was used (See Appendix B). Data were collected via the Satisfaction with Life Scale and Mental Health Continuum during the quantitative phase of the research (n = 521, 52.2% male). During the qualitative phase, semi-structured interviews were conducted with 20 purposively selected participants to gain an understanding of the quantitative findings. Findings revealed that, despite challenges such as poverty, unemployment, and lack of basic services, Ndumo residents exhibit above-average levels of psycho-social wellbeing. The main reasons were that residents are able to live off the land, they feel safe, have hope for a better future, and receive instrumental support from external agents, and internal social support through local churches.

Ndumo, a geographically isolated deep rural community in northern KwaZulu-Natal of South Africa, is a highly traditional, predominantly isiZulu speaking community with a population of 6 779 people (1 505 households), the majority of which is under the age of 19. Politically the Ndumo region, which is mostly governed by traditional authority, falls within the Jozini Local Municipality in the uMkhanyakude District that is situated approximately 650 km east of Pretoria, and 400 km north of Durban (Jozini Local Municipality, 2013-2014; Khumalo, 2014; Statistics South Africa, 2011) (see Figure 8.1). Based on this isolated position, residents refer to themselves as the "forgotten community" (Ogilvie, 2014).

Challenges faced by the community and responses to challenges

The Ndumo area is characterized as underdeveloped, with below-average income levels. By 2010 the poverty rate in the Jozini municipal area was estimated as 75.66% (PRESPA, 2009; Jozini Local Municipality, 2013-2014), resulting in a financially dependent community that greatly relies on social grants. By 2013 the broader Jozini Local Municipal area (inclusive of Ndumo) utilized over 44% of their annual budget for issuing social grants (mostly in the form of pension and child support grants) in the community (South African Department of Agriculture, 2009-2010). This resulted in a dependency ratio of 82.4% among people in the broader uMkhanyakude District (Statistics South Africa, 2011). For survival, in addition to relying on government grants, most households depend on subsistence agriculture and the sale of locally harvested natural resources (Jones, 2006; Jozini Local Municipality, 2013-2014).

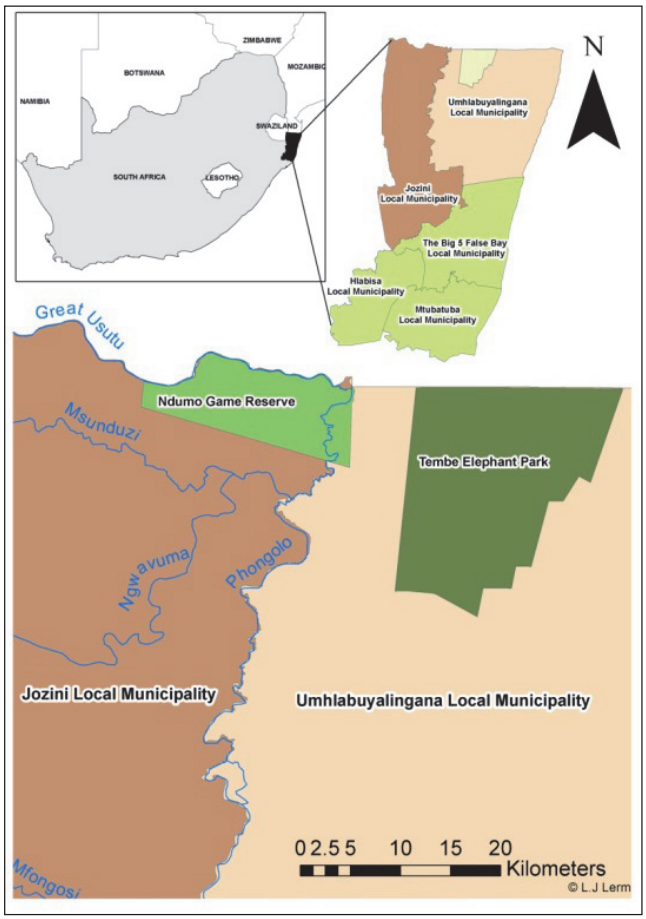


Figure 8.1. Location of the Ndumo community, KwaZulu-Natal (adapted from Mavundza et al., 2011).

The high poverty levels that characterise the Ndumo region are also reflected in the lack of infrastructure and municipal services in the area. At present, access to electricity is either absent or severely limited. There is also a shortage of sources of safe drinking water; water reticulation is currently inadequate and restricted to a few communal taps installed by the municipality (Ogilvie, 2014; South African Ministry of Cooperative Governance & Traditional Affairs, 2010). To compound the challenges already faced by this community, the prevalence of HIV/AIDS throughout the region was estimated by 2003 to be among the highest in the country (Hlongwe, 2003), and was still found to be endemic by 2014 (Jozini Local Municipality, 2013-2014).

However, significant developments with regard to schools and sporting facilities have taken place during the past two to three years. Nine primary schools and six secondary schools are functional within the Ndumo boundaries. Additionally, a number of support mechanisms exist, mainly in the form of medical care provided by several fixed and mobile clinics (Ogilvie, 2014; Khumalo, 2014; Jozini Local Municipality, 2007-2008). Furthermore, Ndumo has been earmarked by the Provincial Government of KwaZulu-Natal for significant development over the next few years, with one billion ZAR being allocated to the construction of a new clinic, a public library, sports field, a large community centre, and new roads in the region (Jozini Local Municipality, 2013-2014).

Psycho-social wellbeing and the Ndumo community

Although some research has been done on socio-economic (Hlongwe, 2003; PRESPA, 2009), socio-ecological (Jones, 2006), health (Jones, 2006) and poverty alleviation (Peters, 2005) aspects in the Ndumo area, very little evidence of the psycho-social wellbeing within the community is available. Increasingly, it is recognized that studies of the objective wellbeing of communities do not provide a complete picture of how a given community is faring. In addition to evaluating objective aspects of quality of life, such as housing, basic services, and the socio-economic condition of communities, it is also necessary to examine a community's subjective and psycho-social wellbeing (Moller, 2012). Such evaluations are particularly important in ensuring the success and sustainability of community development initiatives (Coetzee, 2001). As a construct, subjective wellbeing refers to the extent to which individuals experience the presence of positive emotions, the absence of negative emotions, and the presence of satisfaction with their lives. Whereas the first two components, collectively referred to as affect balance, focus on the affective or emotional dimension of wellbeing, the latter component focuses on the cognitive aspects thereof (Diener, 2009).

Psycho-social wellbeing is an even broader concept, which includes not just subjective (or emotional) wellbeing (EWB), but also encompasses social and psychological wellbeing (Ryff & Keyes, 1995). As conceptualised by these authors, psychological wellbeing (PWB) comprises six dimensions, which include self-acceptance, personal growth, purpose in life, positive relations with others, environmental mastery, and autonomy. Social wellbeing (SWB) is a concept that reflects whether and to what extent individuals are functioning well in their social lives, and comprises social integration, social contribution, social coherence, social actualization, and social acceptance. The most significant distinction between PWB and SWB is that the former reflects how persons view themselves functioning as an "I" or a "me" whereas SWB reflects how individuals see themselves functioning as "we" and "us" (Ryff & Keyes, 1995; Keyes et al., 2008).

Very little research appears to have been conducted on the PWB and SWB dimensions of community wellbeing in the greater Ndumo area (Ogilvie, 2012), and as such, it is unclear how this community is faring in terms of overall psycho-social wellbeing. Furthermore, to date no research has been done to provide an inside perspective of factors that support as well as detract from Ndumo residents' psycho-social wellbeing. Such an understanding is critical in light of the future developments for which Ndumo has been earmarked (Jozini Local Municipality, 2013-2014), in order to ensure that such developments are contextually sensitive and apt. Sentiments on the value of understanding the overall psycho-social wellbeing of communities are echoed by Coetzee (2001) who states that: "development must be firmly based on human wellbeing, and... any development programme will have to focus on ways to uncover people's own definitions of human wellbeing". In light of these research gaps, the following research questions were formulated: What is the psycho-social wellbeing of members of the Ndumo community? Do levels of wellbeing differ across age, gender, and marital groups? What are the factors that most significantly support and/or detract from residents' levels of psycho-social wellbeing?

8.2.2 Method

A mixed-methods sequential **explanatory** design procedure was adopted as basis for the study. During this process, an initial quantitative phase of data collection and analysis is followed by a second phase during which qualitative data are collected and analysed. The purpose of such a design is to use the findings of the qualitative study to explain, refine, or extend the findings that emerge from the initial quantitative data (Plano-Clark & Creswell, 2007). This approach was deemed to be appropriate within the context of the present study

as it would enable contextually sensitive interpretation and explanation of the findings derived via the initial quantitative phase of the project.

Participants

A total of 521 participants took part in the quantitative phase of the study. The characteristics of the participant group are set out in Table 8.1.

Table 8.1. Characteristics of the participants (n = 521).

Item		Frequency	%
Gender	Male	247	47.8
	Female	270	52.2
Marital status	Married	55	10.9
	Single (never married)	413	81.8
	Divorced	11	2.2
	Widowed	26	5.1
Race	African (Zulu and Tsonga)	521	100

These participants all reside within the Ndumo area, which forms part of the Lower Phongolo River and floodplain. The average age of the participants was 37.28 years (SD = 13.12), with ages ranging from 18 to 98. On average, participants had been living in the area for 28.18 years (SD = 16.244).

Twenty participants, all purposively selected on the basis of their experience with and knowledge of the Ndumo community, were interviewed during the qualitative phase of the study. These participants firstly included a focus group consisting of 10 local residents (6 male), aged between 20 and 30 years, and 4 local female residents studying at TUT and residing in the Ndumo area, aged 21, 22, 25 and 31 years respectively. The sample also included a tourism officer at the Ndumo Game Reserve, who is also a local resident, the Ndumo Project Manager who has been actively working in Ndumo and adjacent communities for more than a decade, the Ndumo Game Reserve Manager, an individual who has been doing community based work in the Ndumo community for the past 13 years, and 3 local residents (2 female) working as staff members in the Ndumo Game Reserve.

Data collection

During the quantitative phase, data were gathered by means of a structured questionnaire that was administered by trained fieldworkers. The first section of the questionnaire was aimed at gathering biographical data in relation to participants' age, gender, and the length

of time they had been living in the Ndumo area. To investigate possible correlates of wellbeing, participants' levels of self-reported health and religiosity were also measured. Self-reported health was measured by a single item ("how would you rate your own health?") that was assessed on a 5-point scale ranging from "poor" to "good". Religiosity was likewise measured with a single item ("how religious do you consider yourself to be?") that was rated on a 5-point scale ranging from "not at all" to "very much". This type of question is commonly utilised to assess religiosity, and has been found to be highly reliable as a single-item measure (Chang et al., 2013). To measure wellbeing, two scales were used. First, the Satisfaction with Life Scale (SWLS) (Diener et al., 1985) was employed to measure how residents view their overall happiness and satisfaction with life. The SWLS consists of 5 items, each measured on a 7-point scale ranging from 1 (strongly disagree) to 7 (strongly agree). Responses are summed to obtain an overall score that can range from 5 to 35, with higher scores being indicative of higher levels of life satisfaction. The items in this scale have been found to exhibit good internal consistency, as reflected in a Cronbach's alpha of 0.87, and excellent test-retest reliability, with correlations of as high as 0.82 over a two-month period (Diener et al., 1985). This scale has been used extensively in a South African context and has been found to exhibit robust psychometric properties (Wissing et al., 1999).

Second, the short form of the Mental Health Continuum (MHC-SF) (Keyes, 2008) was used to investigate residents' psycho-social wellbeing. The MHC-SF consists of 14 items that are measured on a 6-point frequency scale ranging from 0 (never) to 5 (every day). In turn, these items fall into three subscales which measure emotional, social, and psychological wellbeing. An algorithm has been devised by Keyes et al. (2008) which enables respondents to be classified as falling into one of three categories ranging from languishing, to moderately mentally healthy, to flourishing; with each successive category reflecting higher levels of mental health and wellbeing. This questionnaire has been validated within the context of a large group of Setswana speaking adults in the North West Province of South Africa and was found to be valid and reliable within this context (Keyes et al., 2008).

During the qualitative phase of the study, data were collected by means of two main strategies. First, a focus group interview was conducted with a group of 10 fieldworkers involved in the quantitative phase of the research. This method seemed appropriate for verifying quantitative findings as the socially oriented research environment of focus groups is helpful for participants to discuss perceptions, ideas, opinions, and thoughts (Krueger & Casey, 2000), and the interactions that occur among the participants can yield important data (Morgan, 1988).

Following this, a series of semi-structured individual interviews were conducted with 10 additional participants who were purposively selected on the basis of their expertise in relation to the main research questions guiding the study (as discussed in the next section). Both the focus group interview and the individual interviews consisted of the following questions, which were based on the main aims of the study, as well as on the findings of the first qualitative phase (discussed earlier) and the quantitative phase of the study: *What makes people/you happy in this community? What makes people/you unhappy/dissatisfied in this community? Why do people want to stay here? What is it that they like/dislike this area? Why? How important is religion to you/the people? In what ways is it important?* Residents who had left Ndumo for educational or other reasons, but who chose to return, were asked: "Why do you come back to this area after being exposed to city life/other opportunities?"

Procedure

During the first phase of the study, entry into the communities was negotiated through a local ward councillor. He also assisted the researchers in sourcing a pool of candidates from which 16 fieldworkers were selected and subsequently trained in administering the survey. The researchers were assisted in this process by an academic assistant who spoke Zulu fluently and was able to translate and explain all concepts to the fieldworkers in their native language.

Fieldworkers were then taken to various locations within the five sub-wards of the Ndumo area, each equipped with multiple copies of the questionnaire, which they administered to local community members during the course of the day. The researchers travelled to the locations where the fieldworkers were deployed and collected the completed questionnaires the following morning, and assessed them for completeness. This process was repeated over the following three days until data collection was complete.

During the second, qualitative phase of the study which took place four months later, fieldworkers were invited by the ward councillor of Ndumo to meet with the researchers and project leader. Ten of the original 16 fieldworkers accepted the invitation, and provided their consent to participate in a focus group discussion.

For all other individuals who were interviewed, a meeting time was either formally arranged, or an informal discussion took place spontaneously with individuals who were available and willing to participate voluntarily during the second research visit to the study area. Prior to all interviews, consent was obtained from each participant to voluntarily participate in the

interview. Notes were taken during all interviews, member checks were done throughout, and transcriptions were summarised and analysed afterwards.

Ethical considerations

In light of the economically disadvantaged reality that characterizes the Ndumo area where the research was conducted, utmost care was taken to ensure ethical conduct during all phases of the study. During the quantitative phase, data collection was done by local community members who volunteered to take part in this process. These volunteers were thoroughly trained as fieldworkers to ensure that data quality would be of a high level, and were reimbursed financially for their services. Furthermore, fieldworkers were specifically trained in explaining the purpose of the research project to potential participants, as well as explaining that participation was entirely voluntary, and that participants could choose to cease their participation at any time, without penalty. All participants who agreed to take part in the study were requested to sign a written consent form after these matters had been explained to them.

During the qualitative phase of the study, in addition to following similar procedures to those outlined above, credibility and trustworthiness of the data were ensured by applying the strategies as described by Shenton (2004) and Leech and Onwuegbuzie (2007), which involved collecting data from different types of participants, and by means of different methods. Furthermore, where possible, member checks were done after interviews to ensure that conversations were captured accurately (Roberts et al., 2006). A thorough description was provided of the research context, in order to allow other researchers to contextualize the findings and to enable decisions to be made on the transferability of the findings to similar contexts.

Data analysis

Data from the questionnaires were analysed in the Statistical Package for the Social Sciences, Version 21 (SPSS 21). Descriptive statistics, principal component analysis, bivariate correlations, independent t-tests and the analysis of variance (ANOVA) test were employed to analyse the data (Field, 2013). During the second phase of the study, qualitative data obtained via the focus group and individual interviews were analysed by means of thematic content analysis, following the procedure as outlined in Corbin and Strauss (2008). During the initial phase of open coding, data were segmented into units of meaning, which were subsequently given a code label by the researcher. During the next, axial coding phase, codes were examined for similarities and differences via a process of constant comparison, and related codes were grouped together into categories. Categories

were then examined for interrelationships, and integrated into overarching themes. Within the context of the mixed-methods sequential **explanatory** design procedure, these findings were then used to explain, refine, and expand upon the findings derived from the initial quantitative phase (Plano-Clark & Creswell, 2007).

Results: Quantitative phase

Table 8.2 provides descriptive statistics, Cronbach's alpha coefficients, and Pearson correlations for the items, scales, and subscales that were assessed via the structured questionnaire in Phase Two.

Table 8.2. Descriptive statistics, reliabilities and correlations between religiosity, life satisfaction, emotional, social, and psychological wellbeing, and self-reported health.

Scale	N	Mean	SD	α	Relig	Swl	Ewb	Swb	Pwb
Relig	511	2.19	1.15	-					
Swl	499	23.47	6.85	.88	.06				
Ewb	490	3.30	1.27	.83	.05	.68**			
Swb	463	3.18	1.09	.82	.04	.66**	.65**		
Pwb	456	3.50	0.96	.86	.06	.60**	.58**	.69**	
Health	511	3.74	1.05	-	-.16**	.20**	.01	.08	.03

Note: Relig = religiosity; Swl = satisfaction with life; Ewb = emotional wellbeing; Swb = social wellbeing; Pwb = psychological wellbeing; Health = self-reported health.

* p<0.05

** p<.01

Relig scale ranged from 0 to 4; Swl scale ranged from 5 to 35; Ewb, Swb and Pwb scales ranged from 0 to 5; Health scale ranged from 1 to 5.

As is evident from Table 8.2 Cronbach's alpha coefficients for all scales and subscales are well above the cut-off point of 0.7 that is customarily proposed for social science research (Field, 2013), indicating that the inter-item reliabilities of these scales are acceptably high within the context of this study population.

Principal component analysis was conducted on the SWLS and the MHC-SF to investigate their psychometric properties. This analysis confirmed that all items in the SWLS loaded onto a single factor (all loadings > 0.62) with an eigenvalue greater than one, and which

accounted for 67.34% of the variance in item scores. In relation to the MHC-SF, two factors with an eigenvalue greater than 1 were found, with a third factor just failing to reach this threshold (0.97). Based on an evaluation of the scree plot, however, this factor was retained, and, along with the first two factors, explained 65.3% of the variance in the scale. The rotated solution, using the direct *oblimin* method, revealed that the items measuring EWB and PWB loaded strongly (all > 0.66) onto their respective factors, but that items from the SWB subscale, while loading onto a third factor, also exhibited cross loadings with the PWB factor in the case of items 6, 7 and 8. In the interest of the overall psychometric structure of the scale, these items were retained, but as a consequence, results pertaining to the SWB subscale should be interpreted with caution, and regarded as subject to future confirmation.

Results of the SWLS revealed that participants' level of life satisfaction was slightly above average (mean = 23.47, SD = 6.85). Similar findings are reflected in the MHC-SF subscale scores, which are all significantly above average. In particular, psychological wellbeing scores were the highest, followed by emotional, and then social wellbeing scores.

The MHC-SF allows researchers to classify participants into a threefold scheme of increasing levels of psychological wellbeing, respectively referred to as languishing, moderately mentally healthy, and flourishing, using a special algorithm (Keyes et al., 2008). As reflected in Table 8.2, 42.2% of the participants were flourishing, 54.7% were moderately mentally healthy, and 3.1% were languishing.

In order to identify community level factors that might account for variations in levels of psycho-social wellbeing, and to contextualize the findings from the wellbeing scales, participants' marital status, gender, religiosity, self-reported health, age, and the number of years they have lived in the Ndumo area were measured and assessed in terms of how these factors related to the psycho-social wellbeing of community members.

Socio-demographic correlates of psycho-social wellbeing

In relation to marital status, findings revealed that only 10.9% of the participants were married, whereas 81.8% were single, 5.1% widowed, and 2.2% were divorced. Given that the average age of the participant group was 37.28 years (SD = 13.12), the low marriage rate was unexpected. Furthermore, in a demographically comparable sample in the North West Province, only 64% of participants were found to be single, with 22% still married, and the remaining 14% divorced and widowed (Khumalo et al., 2012). Levels of psycho-social wellbeing were assessed comparatively according to marital status to determine if any between-group differences occurred. Life satisfaction was found to be significantly lower (*t* =

2.19, *df* = 77, p<.00, two tailed, mean difference = 3.19, 95% CI: 0.29 to 6.09) for those who were widowed (mean = 21.88, SD = 6.95) than for those who were married (mean = 25.08, SD = 5.62).

No statistically significant differences were found between male and female participants on any of the wellbeing-related scales, suggesting that gender does not significantly account for variations in psycho-social wellbeing.

As far as religiosity is concerned, 13.1% of the participants indicated that they were not religious at all, 10.2% considered themselves to be 'slightly' religious, 29.7% were moderately religious, 38.2% described themselves as 'very' religious, and 8.8% indicated that they are extremely religious. As such, 76.7% of participants in this community regard religion as being of moderate to above moderate levels of importance, suggesting that religion likely plays a significant role in the lives of those living in the Ndumo community. However, self-reported religiosity had virtually no bearing on any aspect of wellbeing that was measured, with the exception that those who were more religious were more likely to report lower levels of physical health (r = -.16, p < .001).

In relation to self-reported health, the majority of participants perceived themselves to be in average to above average levels of health. Specifically, 2.2% of participants regarded their health as "poor", 3.5% as "below average", 48.1% as "average", 10.6% as "above average", and 35.6% regarded their health as "good". Whereas a small to moderate correlation was found between self-reported health and life satisfaction (r = .20, p = .00), the three MHC subscales exhibited no significant correlation with self-reported health, indicating that this variable is unlikely to significantly affect psycho-social wellbeing (as measured by the MHC-SF) in this particular community.

A small positive relationship was observed between the age of participants and psychological wellbeing overall (r = .01, p = .04). Closer scrutiny revealed that this relationship only occurred among female participants (r = .13, p = .047), and was not observed among males (r = .05, p = .48).

Finally, no significant correlation existed between psycho-social wellbeing and the length of time that participants had been living in the Ndumo area.

8.2.3 Findings: Qualitative phase

The aims of this qualitative phase of the study were to explain, refine, modify and extend the results that were obtained during the first phase, and to explore the factors that most significantly support and/or detract from residents' levels of psycho-social wellbeing.

Findings largely confirmed those made during the initial phase of the study, with the majority of participants reporting that they consider themselves and their fellow community members to be fairly happy. Six main themes emerged from the data which provided an explanation for Ndumo residents' comparatively high levels of psycho-social wellbeing. However, despite reporting slightly above-average levels of wellbeing, most participants also pointed to the existence of a number of factors in their communities that detracted from their sense of wellbeing. Table 8.3 provides an outline of these themes as a prelude to the discussion that follows.

Table 8.3. Themes emerging from the qualitative phase of the study:

Theme	Subtheme	Verbatim quote
Themes related to factors that support and enhance psycho-social wellbeing		
Finding happiness in the land	Being able to live off the land	*We are happy here… the soil is good for planting and animals have good grazing*
	A good climate	*We like the warmth…the weather is good*
Safety and security related to respect for traditional cultural authority	Safe environment	*We don't mind walking alone…we feel safe*
	Trusting others	*People don't take each other's things…water cans…firewood…we know it belongs to someone who will come and get it*
Support from external sources	Educational	*The children and the teachers benefit from educational workshops and additional programs developed for the specific area…*
	Financial	*The grants help me to buy food for the children…*
	Medical	*The mobile clinics help…otherwise there would not be anything*
	Nutritional	*The e-pap makes a huge difference in the children's lives…only meal they have in a day*
Hope for a better future		*We will never live elsewhere…we love this place…we won't give up, we hope and believe that one day it will be better here for everyone… better services, better living*
Religion and the church	Church and faith	*We go to church to read the Bible and strengthen our faith…the people in the church support each other, especially when someone dies or suffers*
	Traditional beliefs	*The Sangoma will speak to the ancestors and ask for direction…some of us believe in the Sangoma…*
Themes related to factors that detract from psycho-social wellbeing		
Economic challenges	Poverty	*The people here don't have much…they don't have money to buy things…they are poor*
	Unemployment	*We don't have jobs…government does not provide for jobs or much development in this area*
Lack of basic municipal services	No electricity	*We have no electricity, only lamps or candles or fire…for heat and cooking and light…the children study with lamps*
	Insufficient access to water	*We walk to the river…in winter... no water at the taps…we wait a long time in queues for the water*
Problems with education		*I don't think the teachers are good…they sometimes don't even come to school*
Limited and inadequate health care		*The mobile clinic is only here for few hours…we wait a long time and did not get any help. The clinic is very far…*
Always being “last in the row”		*We are always last in the row when they give services*

8.2.4 Factors that support and enhance psycho-social wellbeing

Finding happiness in the ability to live off the land and in a good climate

Participants firstly indicated that they are happy because they are able to live off the land, as the area provides good grazing for livestock, and fertile soil to plant crops such as maize, pumpkin, sugar cane, potato and sweet potato, and also provides natural resources for them to build, find, grow or catch whatever they require for their survival (e.g. fish and some wild). These sentiments are well illustrated in the words of the following participants: "We are happy here… the soil is good for planting and animals have good grazing" and "We plant maize, lots of maize…and pumpkin and potato…the soil is good for potato".

Second, several participants cited the warm, temperate climate as reason for being happy in this area, as is reflected in the following excerpt from an interview with a local resident: "We like the warmth…the weather is good" (also compare the findings in Lankford et al (2010).

Safety and security related to respect for traditional cultural authority

A third major factor that contributed to participants' psycho-social wellbeing in this otherwise impoverished community was the sense of security they felt in relation to their persons and their material possessions. Participants, among whom some were young women, widely reported that they felt totally safe when walking alone in remote areas. In addition to feeling a sense of personal safety, most participants reported that they trusted other residents and had very little fear that their possessions would be stolen by others. For example, many residents left personal belongings such as firewood and water cans in public areas without concerns that these would be taken. One participant stated: "We can leave our water cans at the tap. When we get back there tomorrow, it will still be there. We don't take other people's cans. Also like firewood…you can leave it next to the road". Asked why the crime levels were perceived to be so low, the dominant theme that emerged was that this was as a result of the respect residents had for the *Induna* system (the traditional cultural tribal authority system of the Zulu, (compare Haddad & Maluccio, 2003)). Another consequence of the respect that local residents were reported to have for the *Induna* system was that it resulted in order and discipline in these communities, which also significantly contributed to the satisfaction of many participants (compare Heeg and Breen, 1982).

Support from external sources

Fourth, the psycho-social wellbeing of residents of the Ndumo community is to some extent supported by the provision of financial, medical, educational, and nutritional support from a variety of institutions and individual benefactors. These include government grants

distributed by the local municipality, the provision of mobile health clinics, and educational and nutritional initiatives from The Tshwane University of Technology (TUT) that have established a feeding programme at most schools in Ndumo in 2002. The project has also initiated vegetable gardens at eight schools and in addition, food parcels in the form of "ePap" are supplied to orphans at certain schools (Ogilvie, 2012). Quotes from participants in this regard include: "The grants help me to buy food for the children…" and "The ePap…it makes us very happy. It keeps us healthy and alive. It keeps me going…it is my brain food".

Hope for a better future

Participants were asked why they still like the Ndumo area and want to continue living there despite challenges such as the perceived educational drawbacks and limited job opportunities in this rural community that rely mainly on subsistence agriculture for survival. A central (and fifth) theme that emerged from their responses was that of hope. Specifically, participants stated that they firmly believed and hoped that the poverty that characterizes the area would eventually be eradicated, and that living conditions would improve. In the words of one resident: "We will never live elsewhere…we love this place…we won't give up, we hope and believe that one day it will be better here for everyone…better services, better living. We want to give back to our community…"

Religion

Sixth, community wellbeing appears to be supported in a variety of direct and indirect ways by religion and religious institutions. Whilst a large variety of denominations were mentioned by the participants, Christianity was reported to be the main religion in the area. However, elements of traditional African belief systems, which include beliefs in traditional healers (S*angomas*) and ancestral spirits, were reported to co-exist with Christian beliefs.

Overall, findings echoed those that emerged from the quantitative phase, indicating that religion is important to the majority of participants in the community. This was the case specifically as religion (both in terms of Christianity and indigenous religious belief systems) enabled them to cope with the vicissitudes of life, as it provided moral support, and represented sources of guidance and direction. On a more practical level, the Church and church members were also seen as a source of social and everyday practical support, providing for community members in need. For instance, one participant said: "The people at the church support each other when we suffer…when someone dies or is sick…we talk to each other and take food to the sick because we are from the church". As such, whilst the findings of the quantitative phase of the study revealed no significant relationship between religiosity and psycho-social wellbeing, the themes emerging from the qualitative phase

suggest that such a relationship probably indeed exists, but that it might be mediated by factors such as social support and generativity.

8.2.5 Factors that detract from psycho-social wellbeing

As discussed in the next section, participants also mentioned several challenges that detract from their happiness and wellbeing.

Poverty and unemployment

The first and most dominant theme that emerged centred on the widely reported view that the community is economically underdeveloped and plagued by high rates of unemployment, resulting in pervasive and widespread poverty in the region, as is the case in many other urban areas in South Africa.

Lack of basic municipal services

Second, participants frequently cited inadequate basic municipal services such as a total lack of electricity and limited access to water in most areas as being a primary concern that significantly detracts from their wellbeing. Residents reported that municipal taps are often very far from homesteads (requiring people to walk great distances carrying heavy water cans in order to simply procure water for domestic purposes), and that these taps are reported to often be dry (especially in winter) or to produce virtually no water due to insufficient water pressure, forcing residents to collect water from local rivers.

Inadequate education

Third, participants also expressed their concern at what they perceived to be the inadequate standard of education that residents receive in this area. They indicated that teachers appear to be ill-equipped for their tasks, and generally delivered a poor service. Participants also complained that students receive inadequate instruction in English, which they felt hampered these students' prospects of obtaining work outside of the community. Stated in the participants' own words: "We don't learn English at all…I learned English when I came to university" and "Children cannot speak English…they get training in Zulu and maybe only later in school they start with English, but then also the teachers themselves cannot speak English well". Some participants also felt that it was not only a lack of skill that hampered effective teaching, but also teacher absence at schools: "I don't think the teachers are good… they sometimes don't even come to school". In an interview with a participant who had been doing community-based work in the Ndumo community for 13 years, it was reported that most of the teachers in the area are either unqualified or still in training. Most

teachers are reported to be placed in the Ndumo area against their will and in meagre accommodation facilities, are poorly paid, and consequently lack motivation. Many teachers, and especially principals, are reported to own and operate their own private businesses, which are said to take up much of their time and is the reason why many teachers do not report for work, and therefore pupils are frequently left in classrooms without any adequate instruction and supervision.

Limited and inadequate health care

Fourth, these problems were compounded by what the participants perceived as limited health assistance. Specifically, participants indicated that whilst certain facilities such as mobile clinics were available, the service at these places were often very limited, and residents frequently had to return home after a long waiting period without having received the necessary medication or assistance.

Always being last in the row

Fifth, although the Ndumo area benefits from sponsors, grants, food parcels and other initiatives from institutions and individuals, participants in the community still regard themselves as "forgotten" because they are, as one participant stated: "always last in the row". Most who were interviewed felt that whatever is being done in the province by government or local government, and whenever benefits concerning water supply, education or housing are considered, Ndumo would be last to receive anything.

8.2.6 Discussion

The main aim of Phase Two of the study was to investigate the psycho-social wellbeing of participants in the Ndumo community as so-called "forgotten community". To do so, the mixed-methods sequential **explanatory** design procedure was used which consisted of an initial, quantitative phase, which was followed by a qualitative exploration in order to obtain data that would explain the findings emerging from the initial phase.

Quantitative phase

Results from the quantitative phase indicated that Ndumo residents generally have above average levels of psycho-social wellbeing. The relatively high PWB and EWB scores which were found suggest that participants are likely functioning reasonably well psychologically, and that they are moderately happy. Whilst social wellbeing scores were also significantly above average, it represented the lowest score of all the subscales, suggesting that social conditions might in some cases detract from participants' overall levels of wellbeing.

However, in a study which investigated the psycho-social wellbeing of a Setswana speaking community (n = 459) in the North-West province by using the same scale, far lower levels of especially emotional and social wellbeing were found. Specifically, whilst PWB was found to be relatively high (3.69 compared to 3.50 in the present study), SWB and EWB scores were low (1.98 and 1.58 respectively, compared to 3.18 and 3.30 in the present study) (Khumalo et al., 2012). Similarly, in a study by Keyes et al. (2008) involving a sample of 1 050 Setswana-speaking adults in the North West Province, EWB was found to be 2.6, SWB was 2.4, and PWB was 3.3. Additionally, Keyes et al. (2008) found that 12.2% of participants in their study were languishing, 67.8% were moderately mentally healthy, and 20.0% were flourishing, compared to the present study in which 42.2% of the participants were flourishing, 54.7% were moderately mentally healthy, and 3.1% were languishing. These findings suggest that the social and emotional wellbeing of participants in the Ndumo area significantly exceed those of members of at least some comparable communities elsewhere, and point to the possible existence of a variety of wellbeing enhancing factors extant in the Ndumo community.

Correlational analyses of wellbeing in relation to demographic variables suggested that psycho-social wellbeing was unrelated to gender and the length of time participants resided in Ndumo. In their study, Khumalo et al. (2012) similarly found gender to be uncorrelated with psycho-social wellbeing. Furthermore, despite the fact that 76.7% of participants regarded religion as being of moderate to above moderate levels of importance, religiosity did not exhibit significant correlations with any of the subscales of the MHC or with the SWLS. Taken together, these findings suggest that gender and religiosity are unlikely to substantively impact the wellbeing of residents in these communities, at least as far as these constructs have been conceptualised and measured in these studies.

However, some aspects of psycho-social wellbeing were found to be related to self-reported health, age, and marital status. Specifically, a mild to moderate positive association was found between life satisfaction and health among participants. Whilst the age of the participants had no overall relationship to psycho-social wellbeing, a small positive correlation between these variables was found among female participants. In their study, Khumalo et al. (2012), found age to be unrelated to wellbeing.

Marital status was found to be associated with psycho-social wellbeing in that those who were married had higher levels of life satisfaction that those who were single or widowed. Khumalo et al. (2012) similarly found that married participants reported higher levels of wellbeing than never-married, divorced and widowed participants. However, in the present

study, only about one in ten participants reported being formally married, suggesting that the beneficial effects of marriage would likely be limited to a proportionally small section of the community.

Qualitative phase

The qualitative phase of the study was aimed at explaining and extending the results obtained during the initial quantitative phase of the study, and to identify factors which both support and detract from the community's levels of psycho-social wellbeing. In relation to factors that support wellbeing, the main theme in the area close to the floodplain was that the natural environment enabled participants to make a living in a self-sustaining way (through the provision of rich soil to plant crops, firewood to cook food, good grazing for livestock, and building materials to construct houses) and therefore to survive in spite of the abject poverty that otherwise characterizes the region. It appears likely that these options would not exist to the same degree for members of poor urban communities, where lack of access to land, water, aquatic resources (such as fish) and wildlife would in all probability prohibit the likelihood of living off the land and a River in a self-sustaining way.

A second environmental-related theme that emerged was that the good climate of the area was also viewed as a factor that positively impacted residents' wellbeing. It would appear that mild winters, abundant rain, and warm temperatures increase the habitability of the region, which might not be the case for communities residing in less temperate climates. A third theme was that crime levels were reported to be low, and that residents in the Ndumo community consequently felt safe and secure, which enhanced their psycho-social wellbeing. This situation appears to exist as a result of respect for the *Induna* system and its associated administration of social justice and the discipline of the people in relation to traditional customs.

Fourth, financial, educational, nutritional and medical support from external sources, institutions, and individuals in the form of grants, food parcels, and community upliftment projects, educational initiatives and mobile clinics were found to enhance community wellbeing. However, the fact that the Jozini Local Municipality (2013-2014) used 53% of its budget for social grants raises concerns as to the sustainability of at least some of these support mechanisms.

Hope for a better future was identified as the fifth theme. Such hope helped to sustain a degree of wellbeing and resilience among participants in spite of challenging conditions such as poverty coupled with high rates of unemployment. Additionally, participants were buoyed

up by expectations of continued agricultural self-sustainable opportunities for maintaining their livelihoods.

Sixth, participants also reported that religion and support from the churches contributed significantly to their wellbeing. It was found that participants' religious beliefs represented an amalgam of Christianity and indigenous African religious belief systems. Previous studies confirm the continued existence and relevance of traditional religious belief systems, in particular in relation to the healing powers of the S*angomas* (Hall, 2009; Peltzer et al., 2008). When considered in relation to the finding that high levels of discipline and order existed in these communities as a result of respect of the *Induna* system, these findings point to the important role of cultural and religious factors in sustaining the wellbeing of members of these communities. It appears that a strong, intact, and homogeneous cultural identity and a mainly Christian religious orientation serves to unify community members around a central set of beliefs and cultural systems (such as the *Induna* system), and that it regulates the behaviour of community members in functional ways (such as by reducing the incidence of crime), which in turn, support residents' wellbeing in these communities.

However, despite the higher than average levels of psychosocial wellbeing that were found in Ndumo, the results of the study also reveal that participants in this community face significant challenges that detract from their wellbeing. In particular, poverty, unemployment, and a lack of basic municipal services such as electricity and access to water in many areas seem to reduce psycho-social wellbeing of at least some community members. These findings echo those made in previous studies (PRESPA, 2009; South African Ministry of Cooperative Governance & Traditional Affairs, 2010). Limited and poor quality health-care further compounds the challenging living conditions faced by most participants residing in the area. Finally, concerns about inadequate primary education, teacher competence and motivation, and the absence of any higher education institutions in the region appear to significantly detract from community wellbeing. As such, it would appear that despite educational initiatives that have recently been undertaken (Jozini Local Municipality, 2007-2008), serious shortcomings still exist which require additional investigation and remediation.

8.2.7 Implications of the study

The results of this study point to the importance of various forms of social and other capital, such as a sense of safety, religious communal support, access to social grants, abundant natural resources, and hope in sustaining and supporting the psycho-social wellbeing of residents in otherwise impoverished rural communities. However, with this community being

located in a highly ecologically sensitive area near the Ndumo Game Reserve, and with the Jozini Local Municipality spending 44% of its budget on social grants, these factors also need to be evaluated in terms of their sustainability over time. Furthermore, in spite of recent initiatives aimed at improving access to education in the region (Jozini Local Municipality, 2007-2008), these findings highlight an urgent need for strategies to improve the quality of education, with a specific emphasis on English language education. At present, it appears that a vicious cycle exists, in which what is perceived to be inadequate education and underdevelopment in the Ndumo community results in unemployment and widespread poverty, and a resultant inability to pay for basic municipal services, which hamper community development.

The findings suggest that psycho-social wellbeing in these communities could be substantively enhanced by promoting access to tertiary education or other types of training that will enhance employability of especially the youth in the area, as well as by creating employment opportunities in the region that will benefit the community. With increased income, the provision of basic municipal services such as electricity and access to running water would then become more viable. Given the agricultural basis of the Ndumo community, as well as residents' appreciation for the land on which they live, interventions focusing on the establishment of agricultural initiatives, and on equipping local residents with the necessary skills to succeed in small to medium scale farming enterprises could be explored as potentially viable, contextually sensitive, and relevant strategies for improving quality of life in the region.

The findings of this study also raise the issue of the impact of communities being primarily governed by traditional, rather than local government authority. Future research could investigate the specific ways in which psycho-social wellbeing differs across such communities.

8.2.8 Limitations of the study

As the study was based on a cross-sectional design, no causal inferences can be made about the relationship between variables that have been quantitatively investigated. It is therefore quite possible that the associations that have been found between various aspects of wellbeing and the living conditions and demographic characteristics of residents could be explained by extraneous variables that have not been accounted for in this study. Furthermore, as some of the items purported to measure social wellbeing in the MHC-SF have been found to cross load onto other factors, all findings related to this specific subscale

should be treated with caution, and regarded as subject to confirmation in future studies. Despite the fact that the quantitative sample was large and fairly representative of the community, many of the participants interviewed during the second qualitative phase of the study were young, and in the case of older participants all were employed. This could to some extent have resulted in a marginalisation of the views of older and unemployed Ndumo residents. Though, in phase one of the research, the views of more matured leaders had been considered. Also to take note of is the reality that 70 percent of the Ndumo population is under 29 years of age (Jozini IDP, 2013-2014). Future qualitative studies in particularly Ndumo should perhaps seek to include the views of older participants and especially those of *Indunas* (or elders) in the community. Furthermore, whilst care was taken to ensure that fieldworkers could accurately translate questions into isiZulu (as was the case in the phase one research), in situations where participants could not speak English, the fact that such translation was required at all might have impacted the reliability of the data adversely. A need therefore exists for wellbeing (and other) scales to be translated and validated in isiZulu in order to minimize threats to data reliability and validity.

Any follow-up possibility of the same research effort in Ndumo to other areas in the Jozini Municipal Area that is impacted by the Phongolo River and floodplain was unsuccessful due to the unfortunate circumstance that the team could not in time require any ethical consent and a willingness to do so from the municipality before the expiry of the opportunity to do research in the area.

8.2.9 Conclusion

This study set out to investigate the psycho-social wellbeing of the Ndumo community in northern Maputaland in the KwaZulu-Natal Province of South Africa, using a cross-sectional mixed-methods sequential explanatory design procedure. Overall, the findings revealed that, despite significant challenges such as poverty, poor infrastructure, concerns about education, and inadequate provision of basic municipal services, members of this community do not only exhibit above-average levels of psycho-social wellbeing generally, but appear to fare significantly better in this regard than demographically comparable rural communities elsewhere. The main reasons for this were that community members were able to make a living off the land and liked the climate of the region, that they felt safe and secure in their communities due to low crime levels, that they received financial and instrumental support from external sources, and that they were sustained by hope for a better future. Finally, it was concluded that a strong, intact, and homogeneous cultural identity and a mainly Christian religious orientation serves to unify community members around a central set of

beliefs and cultural systems (such as the *Induna* system), which in turn regulates the behaviour of community members in functional ways, thereby supporting the wellbeing of residents living in these communities.

The research then focused on the level of human-fish interactions as a means of recording and understanding how community members of Ndumo are able to make a living through the practice of fishing and the availability of this natural source as an economic commodity.

8.3 Human-fish interactions in the Ndumo Community

8.3.1 Introduction

The Lower Phongolo River and its floodplain system, is an important reservoir for a number of fish species. Phase Three of the study set out to gain an understanding of the potential impact of the Ndumo community on the local fish population by investigating the interactions between local residents and fish (See Appendix C). The study followed a sequential, exploratory, mixed-methods design comprising a qualitative phase where interviews, observations and document reviews resulted in the development of a questionnaire based on emerging themes, which was followed by a quantitative phase during which results from phase one were verified and quantified by a survey. The results of this study suggest that human-fish interactions in the Ndumo community are significant, and play an important role in supporting the livelihood of members of this community, both by serving as an important form of sustenance, and by constituting an important economic resource (Nell et al., 2013). However, given the ecological sensitivity of the floodplain, which has been declared as an international RAMSAR wetlands site, it was also deemed necessary to assess the impact that these interactions might have on the fish populations in the region.

Human-fish interactions are as old as humanity itself (Bogue, 2001; Jacobsen et al., 2004; Knox, 1954; Whitelaw, 2009). Throughout southern Africa, wetlands in particular are important sources of fish because they support numerous small-scale fisheries, especially in rural communities (Turpie et al., 1999). These multi-species fisheries are generally highly productive and constitute a major contributor to the livelihoods of many local communities (Baker, 2008; Neiland & Béné, 2006; ACWR, PLAAS & UWC, 2012), especially in the large lake systems in central and eastern Africa (Heck et al., 2007). As early as 1994, Ribbink reported that fish caught from Lake Malawi provide as much as 75% of the animal protein consumed in the entire country, which is a finding also supported by more recent studies

(Heck et al., 2007). The relative importance of fish as food and as a source of livelihood for local communities can therefore not be ignored or denied.

In South Africa, however, the relative scarcity of large floodplain wetlands means that wetland fisheries are not experienced as generating high levels of fishery productivity, with the exception of some of the larger systems such as the Phongolo floodplain (Acreman & Hollis, 1996; Merron & Weldrick, 1995; Ross & Ross, 2012). The Ndumo Game Reserve is of critical importance for the conservation of fish in the Lower Phongolo River and its floodplain system since this Reserve acts as an important reservoir for species such as the tigerfish *Hydrocynus vittatus*, which is a protected species in South Africa (Heeg and Breen, 1982; Smit et al., 2013). The ecological value of the Phongolo River floodplain, and particularly the varying natural and anthropogenic impacts on the system, has already been recognised in both public and scholarly circles decades ago. For example Breen et al. (1973), pointed to the effects of water management and floods on the system, while Heeg and Breen (1982) in turn highlighted the impact humans may have on the floodplain.

Recently, a few additional studies were conducted on human activity in this region, and the various ways in which such activities affect the ecosystem of the Phongolo floodplain (Chhotray, 2010; Ellender et al., 2010; Lankford et al., 2010; PRESPA Report, 2009). The importance of fish in particular was highlighted, as it was found to play an important role in the livelihood of local communities in the area, inclusive of fishing practises close to storage dams such as Pongolapoort Dam (ACWR, PLAAS & UWC, 2012). This finding was further supported by the results of Ross and Ross (2012), who asserted that fish was the main protein source in the floodplain area. However, whilst there seemed to be general consensus about the importance of fishing in the context of communities located in the region of the floodplain, far less is known about factors such as the types of species most commonly consumed, seasonal variations in fishing and fish consumption, and the nature and extent of local trade in fish. In a current WRC study (ACWR, PLAAS & UWC, 2012) fishing practices in storage dams in selected areas of South Africa are investigated, which includes the Pongolapoort Dam. This study did not investigate fishing practices further north towards Ndumo.

Given the ecological sensitivity of the Lower Phongolo floodplain, and the possible pressures that human-fish interactions in the region might exert on local fish populations, it was deemed important to assess such interactions in the Ndumo community. This community was selected as Ndumo represents a large human settlement in the northern parts of the floodplain region within South Africa. Reference to the Mbangweni and Tembe people (Heeg

and Breen, 1982; Naguran, 2010, p.8). Because of the claim that overfishing in the area outside the Ndumo Reserve is said to have resulted in breeding stocks been greatly reduced since Heeg and Breen conducted their 1982 study (Jozini IDP 2013/14; Lankford et al, 2011), it made sense to revisit a selected area in the research process to obtain some substantial information on human-fish interactions from the community themselves.

Based on the above, the aims of the present study were to investigate various aspects of human-fish interaction in the floodplain region, focusing on fish traders, fish consumers, and fishermen and women.

8.3.2 Method

A sequential, exploratory, mixed-methods design (Plano-Clark & Creswell, 2007) was adopted as basis for the study. It consisted of three phases: (1) a qualitative phase to explore people's interactions with natural resources, particularly fish (as already discussed in section 8.1); (2) the development of a second questionnaire on the basis of the qualitative findings in the broader Jozini municipal area as well as in the Ndumo community (see section 8.2); and (3) a quantitative phase to verify and quantify the results (especially related to community's association or interaction with fish) as will be discussed in this section. This design is commonly used in cases where contextual sensitivity is required and where limited empirical knowledge exists (Plano-Clark & Creswell, 2007). Two additional benefits of this approach are that it reduces bias and increases credibility, because the investigators only work with what emerges during interactions with the participants and these views are confirmed and tested against the views of a more representative sample.

Participants

During the quantitative phase of the study, 521 participants were surveyed. Their average age was 37.28 years (SD = 13.12), and participants had been living in the Ndumo area for a mean 28.18 years (SD = 16.24). As shown in Table 8.4, the participant group consisted of an almost equal number of males and females who were mostly single (i.e. not formally married) and isiZulu and/or Tsonga speaking. Of the total group, 88.90% viewed themselves as consumers of fish, 28.98% as local fishermen or fisherwomen, and 38.69% as fish vendors.

Table 8.4. Characteristics of participants (n = 521)

Item	Category	Frequency	Percentage (%)
Gender	Male	247	47.8
	Female	270	52.2
Marital status	Married	55	10.9
	Single (never married)	413	81.8
	Divorced	11	2.2
	Widowed	26	5.1
Race	African (mostly isiZulu and Tsonga)	521	100
Participant category	Consumers of fish	463	88.9*
	Fishermen/fisherwomen	151	28.9*
	Fish vendors	203	38.9*

**As several participants fell into more than one category, percentages do not add up to 100.*

Procedure

Entry to the Ndumo community (i.e. various villages) was negotiated on behalf of the research team by an experienced research assistant who introduced himself and carefully explained the purpose of his presence to the various leaders (as a representative of the research team), what the team planned on doing in the area, and what their involvement would entail if they agreed to participate. Semi-structured interviews were then conducted with those participants who provided their informed consent.

This work was followed up with a second visit to the area during which the questionnaire that was developed was used to quantify and verify the initial results. A group of 16 fieldworkers was sourced from the various local villages and trained to recruit participants, obtain informed consent, and administer the questionnaire by means of structured face-to-face interviews.

All quantitative data were collected over a five-day period, with fieldworkers receiving a set of questionnaires in the morning, which they administered during the course of the day. Questionnaires were collected at the end of each day and examined for completeness.

During the entire process of data collection, care was taken to do so in as ethical a manner as possible. Informed consent of all research participants was obtained, and it was explained to respondents that their responses would be treated confidentially and that they had the right to withdraw from the research at any time without penalty.

Data collection

Qualitative data were gathered by means of interviews, observations, and a document study. Non-participant observations were made during both visits to the study area and documented. These data were later used as contextual information. A document study, as performed by one of the members of the research team, was used as background information and a knowledge base against which the results of this study were compared and contextualised.

Semi-structured interviews were used to collect data, as outlined in Creswell (2007). The interviews consisted of six open-ended questions aimed at eliciting the participants' views on various aspects pertaining to the utilisation of natural resources in the area, followed by more direct questions relating to participants' interactions with fish. If deemed necessary, follow-up questions were asked to explore or clarify participants' responses. Questions included:

- *What does the floodplain mean to you/the community? (How so?).*
- *What forms/kinds of natural resources do people in your community utilise from the floodplain (on a regular basis/only at times)?*
- *How does your community use/utilise these natural resources economically/politically and culturally/religiously?*
- *How important are these natural resources for each family's survival or coping with life?*
- *Can you please tell me more about the fish industry in your area?*

The participants' responses were digitally recorded and transcribed to ensure accuracy.

Quantitative data were collected by means of a structured questionnaire, which was developed on the basis of the themes that emerged from the analysis of the qualitative data. It consisted of 40 questions that were divided into four sections:

- Section A consisted of four basic demographic questions aimed at determining the age and gender of the participants, followed by questions to establish where the participants resided and how long they had been living in the area.
- Section B was specifically aimed at consumers of fish products and included a question on the proportional use of various types of proteins in their diet, followed by more fish-use-related questions such as how many times per week and per day participants ate fish, why they ate fish and whether their diets changed at different times of the year and, finally, questions such as how and where they obtained the fish, which species of fish they consumed, and whether fish and fishing had any cultural or social significance to them (participants were given the local names of

each fish species, and were shown full-colour photographs and sketches of each species to assist with identification of these).

- Section C of the questionnaire, which was aimed at local fishermen and women, included questions relating to the number of years these participants had been fishing in the area, where they caught most of their fish, the number of locations at which they fished, the availability of fish, how they selected the sites where they fished, why they fished, the methods they used to catch the fish, whether they had experienced any recent changes in the availability of the type and size of fish, the type of species they caught, whether they had ever noticed any large-scale deaths of fish, whether fish played an important social or cultural role in their lives, and concluded with a question on aspects that made it more difficult for them to fish.
- The final section of the questionnaire was directed at fish traders and/or people who sold fish but who were not themselves fishermen or fisherwomen. The first question in this section was used to determine how many years they had been selling fish, followed by items inquiring about the availability of fish, the form in which the fish was sold, where participants obtained the fish from, the types of species they sold, and whether they had experienced any changes regarding the availability of certain species.

Data analysis and interpretation

Qualitative data were analysed by means of thematic content analysis (Creswell, 2007). To begin with, the data were subjected to a process of open coding during which descriptive codes were assigned to fragments of text. Following this, codes were inductively grouped together into categories based on conceptual similarities as part of a selective coding procedure. Finally, each category and each theme were studied in detail again to make sure that the original data truly supported these categories. In turn, these categories were used as a basis for the development of the questionnaire used in the quantitative phase of the study.

Data from the quantitative questionnaires were analysed in the Statistical Package for the Social Sciences, version 21 (SPSS 21). Basic descriptive statistics were calculated for all items in the questionnaire. Wherever relevant, findings were compared across demographic groups, using independent t-tests to verify the statistical significance of any differences that emerged, while bivariate correlations were used to examine relationships between variables (Field, 2013).

Given that the qualitative phase was mostly exploratory, that the findings from this phase were incorporated into the quantitative survey, and that the main aim of the study was to obtain representative and generalisable findings, only quantitative results are reported on in this section.

8.3.3 Findings

The results pertaining to the consumers of fish are reported first, followed by those of local fishermen and fisherwomen and, finally, those of fish vendors.

Consumers of fish

As can be observed in Table 8.5, which outlines participants' dietary preferences in relation to sources of protein, fish was found to be the third most frequently consumed protein by males and females alike. Among those who consumed fish, which included 88.9% of the participant group, fish was eaten on average twice a week. On days when fish was eaten, participants ate fish on average 1.4 times per day (SD = 0.59). Most participants relied on chicken and, to a slightly lesser extent, on beef as main protein sources. Goat meat, venison (referred to as "bush meat") and mutton were also consumed, but relatively infrequently and far less often than fish. To enable identification of additional protein sources, a category of "other" was included. A qualitative analysis of findings relating to the latter revealed that respondents occasionally utilised rabbit as a protein source.

Table 8.5. Frequency of the consumption of various protein sources by residents of the Ndumo area.

Protein source	Mean	*SD*
Chicken	3.91	1.10
Beef	3.11	1.13
Fish	2.70	1.10
Goat	1.98	0.79
Venison (bush meat)	1.66	0.98
Mutton	1.65	0.95
Other (mainly indicated as rabbit)	1.78	1.18

Consumption was measured on a five-point scale ranging from "never or almost never" (1) to "almost daily" (5) in response to the question:* "How often do you eat each of the following*?"*

Overall, these findings suggest that whilst fish did not constitute the primary protein source in these communities, it is nonetheless consumed quite frequently and in significant quantities by the majority of participants. As such, fish plays an important role in the overall diet of residents in the Ndumo community. Additionally, participants were also asked which species of fish they ate and how frequently they did so. Table 8.6 provides a summary of these findings.

Table 8.6. Percentage of participants who consumed the species as listed and mean number of fish/crayfish consumed per week.

Species	Percentage of participants who consumed species	Mean number consumed per week	SD
Coptodon rendalli	89.1%	4.17	3.16
0reochromis mossambicus	77.4%	4.28	2.92
Synodontis zambezensis	64.0%	3.15	3.30
Clarias gariepinus	54.8%	3.81	3.98
Schilbe intermedius	54.8%	2.85	2.64
Hydrocynus vittatus	46.9%	2.59	2.65
Cherax quadricarinatus	20.9%	2.27	2.10

Overall, it was found that all species of fish (listed in Table 8.6) were consumed in significant quantities by a substantial portion of the participant group, with the exception of the recently introduced alien freshwater crayfish *C. quadricarinatus* (see Du Preez and Smit, 2013 for a report on this alien). Reasons for the low levels of utilisation of this (invader) species are still unclear and should be examined more closely in future studies. The two tilapia species that occur in the region were the most preferred species of fish, with *Coptodon rendalli* being significantly more preferred than *0reochromis mossambicus*. Unsurprisingly, these species were also the most frequently consumed species of fish. However, while *Clarias gariepinus* was consumed by only 54.8% of the participants, it was eaten the third most often of all species. A possible reason for this trend may be that *C. gariepinus* is large, omnivorous (taking a variety of bait), long-lived and fast-growing, and attains sexual maturity within two years. Due to the presence of their accessory **air breathing** organs, it is able to absorb oxygen from atmospheric air (Booth et al., 2010). These attributes allow *C. gariepinus* to survive in most adverse conditions and could, therefore, explain its abundance. Differences such as that males ate more S*chilbe intermedius* (mean difference = 0.54) and *Cherax*

quadricarinatus (redclaw crayfish) (mean difference = 0.47) than females were not statistically significant (t = 1.51, df = 213.90, p = .13, equal variances not assumed; 95% CI: -0.17 to 1.24 and t = 0.89, df = 62.42, p = .38, equal variances not assumed; 95% CI: -0.59 to 1.53, respectively).

Bivariate correlations were used to examine the relationships between age, the number of years that participants resided in the Ndumo area and their consumption of fish, both generally and in relation to specific species. Age was uncorrelated with general fish consumption, but a small negative correlation (r = -.13, p = .006) was found between the number of years participants lived in the area and the number of fish they consumed per day. However, when specific species were considered, it was found that the longer participants lived in the Ndumo area, the more likely they were to eat *C. rendalli* (r = .12, p = .02), *S. zambezensis* (r = .15; p = .02), *O. mossambicus* (r = .13, p = .02), and, especially *H. vittatus* (r = .24, p = .00), suggesting that those living in this region develop an acquired taste for these species. A positive correlation (r = .17, p = .00) occurred between self-reported health and fish consumption, suggesting that eating more fish was associated with elevated levels of self-reported health.

All participants who indicated that they did consume fish were asked what their primary reasons were for doing so. In descending order of importance, 57% of participants asserted that they ate fish as they regarded it as healthy; 41.1% said they consumed fish because they like the taste thereof; 21.9% stated that they preferred it as it was fairly cheap and affordable; 15.5% thought it was easily available, while 10.6% felt it was quick and easy to prepare. Only 9.4% of participants (of which the majority (75%) were males) indicated that they ate fish because they could catch it for free. The above-mentioned figures strongly suggest that the appeal of fish does not necessarily lie in the fact that it is relatively freely accessible in the surrounding environment, but rather in its taste and perceived health benefits.

Asked how they obtained the fish they consumed, 46.1% of participants (54.4% of females and 37.3% of males) indicated that they bought it from a vendor; 37.8% (similar for both genders) obtained it from family and/or friends, whereas 16.1% (25.5% of males and 7.2% of females) caught it themselves. A chi-square test with cross-tabulation confirmed that the association between gender and vendor (where participants obtained fish) was significant ($\chi^2(2, N = 457) = 31.18$, p = .000), and of moderate strength (Φ = .26). Among those who indicated that they bought fish, 58% indicated that they purchased fish from a vendor in the Ndumo area's local village, whereas 19.5% typically obtained fish from a vendor in a nearby

town, and 14.1% bought fish from vendors who sold their merchandise close to main roads (but not within any designated town or village between Jozini and Ndumo). A small number (8.4%) of the respondents bought fish from other unidentified sources.

Participants were also asked whether they had experienced any significant changes in the price of fish over the past 10 years. A virtually unanimous response to this question was that prices had increased slightly.

In an attempt to obtain a thorough understanding of the possible cultural role pertaining to fish and fishing among the Ndumo communities, participants were also asked whether they were aware of any social or cultural activities or rituals (apart from the continued use of traditional fishing tools and methods) in which fish or fishing plays an important role. Overall, 85.8% of participants stated that they were not aware of fish-related cultural activities, implying that fish and fishing have instrumental value as a food source, rather than a cultural value.

Local fishermen and fisherwomen

A total of 149 local fishermen and fisherwomen were surveyed as part of the study. Of these, 89 (59.7%) were men and 60 (40.3%) were women. Each of these participants on average spent a mean 9.25 years (SD = 7.78) fishing in the Phongolo floodplain in the general vicinity of the Ndumo area. Participants indicated that they commonly fished in an average of 4.32 (SD = 5.07) different locations. However, the majority of participants (70.48%) only fished in one to three locations. Among these sites, 81.02% of fish was caught in rivers and streams; 13.60% in pans, and 1.9% in other (unspecified) locations, suggesting that fishing was mostly focused around the river system and that the pans were not highly exploited for fishing. The main reason for this seems to be that the majority of the pans in the Ndumo region falls within the confines of the Ndumo Game Reserve and, as such, are protected. Utilisation of fish in unprotected pans further south should be more thoroughly investigated in future studies.

Participants were asked why they preferred the aforementioned (unspecified) fishing locations to other possible locations. The most commonly cited reason, stated by 33.59% of the participants, was that the frequent availability of fish in a given location was the most decisive factor in their choice of fishing spot. The second most common reason, cited by 31.35% of participants, was the ease with which they could fish in a given location, based on factors such as a lack of obstacles and the likelihood that fishing lines could become

ensnared. Participants also indicated that the physical safety of the fishing spot (22.19%), and its proximity and accessibility (12.83%) were significant considerations in their choice.

Along a somewhat similar vein, participants were asked about factors that made it more difficult for them to catch fish. In descending order of importance, they indicated that the most significant challenges were that the pans and the rivers sometimes dried up (77.5%), that there were too many other fishermen (74.0%), that there had been fewer fish in the pan and river recently (64.0%), that the release of water from the Pongolapoort Dam interfered with fishing (48%), and that it became difficult to fish when it rained a lot (45.5%).

In order to ascertain whether seasonal variations in the abundance of fish were experienced, participants were asked whether they caught more fish at some times during the year rather than at other times. The majority (63.7%) stated that they caught fish mostly in summer, whereas 22.6% indicated that they caught fish mostly in winter. Around 5.5% of participants specified that there were no seasonal changes, and thus no particular choice of season to be preferred, while 8.2% said that they caught more fish at certain times than at others but that this was not seasonally related.

Participants indicated that the bulk of fish that was caught were intended to be sold (54.73%) and that 44.28% of fish caught was for personal consumption. One percent of participants indicated that fish was caught for other, unspecified uses. It was also found that males were more than twice as likely as females to catch fish for personal consumption, whereas females were a third more likely to catch fish for commercial reasons.

A variety of methods was used to catch fish. Most commonly employed were hand-lines (26.77%), traditional baskets (25.81%), and drag nets (22.26%), followed by gill nets (17.10%), and to a much lesser extent, fishing rods (8.19%). The species of fish usually caught by participants and the average number of fish per species that was caught are summarised in Table 8.7:

Table 8.7. Summary of type of species caught and number of each species caught in an average week.

Species	Percentage of participants who indicated that they actively caught this species	Mean number of each species caught in a typical week	SD
Coptodon rendalli	97.1%	23.86	33.83
Clarias gariepinus	85.5%	14.71	16.62
0reochromis mossambicus	78.9%	19.22	27.19
Synodontis zambezensis	73.7%	16.51	25.21
Schilbe intermedius	72.9%	12.24	15.31
Hydrocynus vittatus	59.0%	11.11	14.93
Cherax quadricarinatus	31.8%	6.92	8.70

Coptodon rendalli, and to a lesser degree *O. mossambicus,* again emerged as the most-caught species of fish in the region. Whilst the majority of participants indicated that they actively sought to catch *C. gariepinus*, a significantly lower number of these fish was caught. However, as can be seen from the large standard deviations associated with the number of fish caught, great variability exists in this regard, with some fishermen and fisherwomen catching one or two fish per week and one individual reporting catching as many as 200 fish of the tilapia species per week. These differences could possibly be attributed to the fact that some fishermen fished for personal consumption and, therefore, only needed a relatively small number of fish, whereas others did so for commercial purposes and, therefore, made far larger catches. No statistically significant gender differences were found in relation to the types or numbers of fish species caught.

The only notable gender difference that occurred in relation to the type of species that was caught was that males reported catching more *H. vittatus* than females (mean difference = 7.3 fish per week). However, this difference failed to reach statistical significance (t = -1.71 df = 58 p = .09 two-tailed; 95% CI: -16.04 to 1.28).

In order to determine whether any changes or trends pertaining to the fish population had been observed by local fishermen, participants were asked whether they had noticed any changes in the number and size of fish over the past 10 years. Responses were measured

on a five-point scale ranging from “decreased a lot” (1) to “increased a lot” (5). A score of 3 indicated that there was no observed change. Participants’ mean score was 2.91 (SD = 1.22), suggesting that they observed very little change. The same was true for the average sizes of the fish, which were viewed as only decreasing fractionally (M = 2.89; SD = 1.25).

Fish traders

Lastly, data were also collected from participants who sold (but did not themselves catch) fish. Of the 203 fish traders surveyed, 52.2% were female and 47.8% were male. The average trader indicated that he or she had been selling fish in the area for 7.50 years (SD = 5.87) and that they obtained 85% of the fish from local fishermen and 15% from other undisclosed suppliers.

Congruent with what was reported by fishermen, the majority (62.6%) of fish traders also reported that there was significantly more fish available in summer than in winter, although 20.6% of traders believed the opposite to be the case. A further 12.1% of participants indicated that the availability of fish fluctuated according to other undisclosed factors not related to the seasons. Finally, a small number of traders (4.7%) stated that the availability of fish remained more or less the same all year round.

Asked whether they had experienced any changes in the availability of fish over the past 10 years, participants indicated that virtually no such change had been noticed by them (mean score on five-point scale ranging from “big decrease (1)” to “big increase (5)” was 3.20 [SD = 1.31]).

Traders indicated that they mostly sold their fish in nearby towns (40.7%) (sold regularly in Ndumo but occasionally in Jozini, approximately 75 km further south) and in their own villages (30.7%); also to a lesser extent in other villages (where they did not reside) (15.9%), or “next to the road” (referring to areas outside towns or villages) (11.1%).

The format in which fish was sold was predominantly fresh (50.20%) or deep-fried (33.47%) and, to a lesser extent, dried (15.54%). Female fish traders were slightly more inclined to sell fish fried than were males, and male traders were slightly more inclined to sell their fish fresh.

Table 8.8 indicates the number of fish that was sold by traders during the course of a typical week, and mean and modal prices per average sized specimen for each species.

Table 8.8. Number of fish sold by traders during a typical week and mean and modal prices per average-sized specimen for each species.

Species	Mean number sold per week	Mean price per fish	Modal price per fish
0reochromis mossambicus	29.02	20.30	10
Coptodon rendalli	28.87	18.75	10
Clarias gariepinus	20.05	23.88	20
Hydrocynus vittatus	18.02	13.85	10
Synodontis zambezensis	17.84	13.87	10
Schilbe intermedius	15.64	14.03	10
Cherax quadricarinatus	13.92	16.76	15

The findings reported in Table 8.8 suggest that the two tilapia species and *C. gariepinus* were both the most frequently sold and were also the most expensive of all the fish species that were exploited in the area. However, when the modal (as opposed to mean) prices for all species of fish were considered, it would appear that fish of all species was most commonly sold for ZAR 10 (with the exception of *C. gariepinus*, which was sold for a modal amount of ZAR 20, and the redclaw crayfish, which was sold for a modal amount of ZAR 15 per fish). As such, these species likely play a significant role in the context of the local economy within the Ndumo area and the greater Phongolo River floodplain region.

8.3.4 Discussion

This study was conducted to obtain an informed understanding of human-fish interactions in the Ndumo area of KwaZulu-Natal. Quite a number of relevant findings emerged that could help to clarify the way in which people living in this area interact with fish and the potential impact their interactions – be they consumers, fishermen/women or traders – could have on local fish populations. First, it was found that fish only constitutes the third most regularly consumed protein source (after beef and chicken). This contradicts earlier findings by Ross and Ross (2012), who stated that fish was the main protein source in the floodplain area. The results of this study suggest that fish is mainly used as a supplementary protein source,

at least in the Ndumo area of the floodplain, given the quantity and frequency of fish consumption that were reported by participants.

Participants indicated that fish was fairly affordable (said to be typically around ZAR10 per average-sized fish) and also indicated fairly unanimously that fish prices had increased only slightly over the past 10 years. It was also found that consumers have not experienced any significant changes in the number and availability of fish. In addition, the participants identified a previously unrecorded source of protein: rabbit – indicating that they are willing to adapt their dietary preferences to what is locally available. Furthermore, participants indicated that fish is mostly consumed for its perceived health-related benefits and its taste, rather than perhaps because it seems to be a freely available resource. It could well be that local people are more aware of the health benefits of fish as a result of education and nutritional campaigns being stepped up (Ogilvie, 2014).

Most consumers also indicated that they bought their fish from vendors in their own villages or in a nearby town (but usually in Ndumo) or obtained fish from friends and family members who had personally caught the fish. This suggests that the local fishing industry, though limited in opportunities, contributes directly and significantly to the economy of the Ndumo area, in which income-generating opportunities are very scarce (Ogilvie, 2014). These findings correspond with those made by Andrew et al. (2010) in relation to communities in the Fish River Valley, Eastern Cape Province. The latter found that, given the catches maintained during the time of their study (2010), fishing activities had the potential to generate an estimated profit of over R50 000 per annum for an area with few other economic opportunities. Preliminary findings in a recent study which investigated fishing practices in impoundments in seven South African provinces indicated that small-scale commercial fishers earn between R500 and R2 500 per day (ACWR, PLAAS & UWC, 2012).

It was also found that the most preferred fish species were *C. rendalli* (red-breasted tilapia*) and O. mossambicus* (Mozambique tilapia), followed by *S. zambezensis* (brown squeaker), *C. gariepinus* (sharptooth catfish) and, to a far lesser extent, *H. vittatus* (tigerfish) and *C. quadricarinatus* (redclaw crayfish). None of these species are regarded as threatened or endangered, with the exception of *H. vittatus*, which is a protected species in South Africa. However, even though residents tend to increase their consumption of this species the longer they reside in the Ndumo area, this species is eaten fairly infrequently, and does not appear to be specifically targeted as much as being incidentally caught. *Cherax quadricarinatus* is an invasive species, and catching this species for personal or commercial

use is currently not classified as illegal, although this species has the potential to have a large impact on the local fish population (Smit et al., 2013).

In the case of consumers, it was also found that fish plays an important role given its instrumental value (as a source of either food or income) rather than playing a cultural role in their daily lives (apart from the continued use of traditional fishing tools and techniques). This finding stands in contradiction to that of a previous study on the Phongolo floodplain which indicated that there are certain cultural practices around fishing habits if fish stocks are sufficient (Lankford et al, 2010; Lankford et al, 2011). Additional research would be required to clarify these contradictory findings and to investigate the possible cultural significance of fishing in the Phongolo floodplain region.

Fishing in the floodplain region, which was slightly more likely to be done by men rather than women, primarily took place in the Phongolo River, and to a much lesser extent in the more ecologically sensitive pans. This suggests that local communities might not have a large impact on the pans in the Ndumo area. However, as most of the pans in the Ndumo area fall inside the boundaries of the Ndumo Game Reserve and, as such, are protected, and as participants might not have disclosed any illegal fishing activities, additional research is required to investigate the extent to which these, and other unprotected pans in other parts along the Phongolo River's boundaries are exploited for fishing.

Significantly, too, those who fish tend to focus on more than one site (an average of 4.3 sites), and selected these sites predominantly on the basis of the location's fish abundance and the ease of fishing there. It also appears as though there is a peak during summer months and that fishing activities decrease during the colder months. This could potentially allow fish stock to recover at given sites and are likely to decrease the impact on a given site.

A variety of methods was used to catch fish, which included (in decreasing order of prevalence) hand-lines, traditional methods (using baskets), drag nets and, to a lesser extent, gill nets. Fishing rods were used least often. Thus, non-commercial techniques were used, and no evidence of large-scale fishing was uncovered – indicating that local communities in the area (especially then the male population) fish for personal subsistence rather than for commercial reasons. More specifically, slightly less than half the number of fish caught were consumed by the fishermen and their families, and the remainder was sold for subsistence purposes. The recent preliminary finding of the ACWR, PLAAS & UWC (2012) report also revealed that traditional and modern methods of fishing were found to co-

exist, and that fishing in rural areas was done both for survival and small-scale subsistence purposes.

Furthermore, given the number of fishing methods available, hand-lines are by far the least destructive method, and is a low-impact and selective way of fishing.

Asked about the most significant challenges experienced in fishing, participants mentioned that, owing to pans and rivers drying up, they had to compete with many other fishermen and fisherwomen, and that there was a gradual tendency for fewer fish to be found in the rivers and pans. However, in response to another question, most participants indicated that they had noticed only a very slight decrease in both the number and the average size of fish in the rivers and pans over the past 10 years.

A more or less equal number of male and female fish traders did not generally fish personally but mostly obtained fish from other local fishermen and fisherwomen in Ndumo or neighbouring villages in the area. Most traders sold their wares either in a nearby town or, somewhat less often, in their own villages. Fish was either sold fresh or deep fried and, occasionally, in dried form. The most commonly sold fish and those also fetching the highest prices were *C. rendalli*, *O. mossambicus* and *C. gariepinus*. Where fish vendors differed from the other two role-players was that they reported selling slightly more *O. mossambicus* (Mozambique tilapia) compared to other *species.* This could probably be attributed to misidentification, since *O. mossambicus and T*. rendalli have very similar appearances when they are not in breeding colours, especially after being caught, which causes the natural coloration of the fish to fade.

Assessing the impact of human activities on fish populations in the Ndumo area is hampered by the fact that very little research has been conducted to determine the size and reproductive rate of the fish population in this ecologically sensitive region. This study has a few limitations. Given the cross-sectional design of the study, no inferences can be made in relation to causality between variables. Furthermore, it is possible that some degree of response bias might have occurred in some instances in relation to the disclosure of the extent to which illegal activities such as hunting and fishing in protected areas were practised.

8.3.5 Conclusion

The results of this study suggest that human-fish interactions in the Ndumo community are significant, and play an important role in supporting the livelihood of members of this community, both by serving as an important form of sustenance, and by constituting an important economic resource. However, given the ecological sensitivity of the floodplain, it is also necessary to assess the impact that these interactions might have on the fish populations in the region. It is hoped that the findings of this study will provide the necessary information on fish consumption so that the impact of fishing on fish reserves in the Ndumo area can be assessed once fish population studies have been conducted. Extended research on human-fish interactions in the southern parts of the Phongolo floodplain region and in other fish reserves in the broader peripheries of the floodplain should be seriously considered, to fully understand human habits regarding fish consumption. Given the sensitivity of the floodplain ecosystem, continuous monitoring of this situation is important to ensure that human-fish interactions in the region remain sustainable.

8.3.6 Summarising remarks

In this study, the lifestyle, culture and daily activities of the Ndumo community (general wellbeing and particularly fishing habits in the context of social, cultural and economic aspects) were explored, in particular, community's impressions (opinions) about the value of the floodplain fishery (subsistence vs. commercial).

In relation to participants' views regards the Lower Phongolo River and floodplain, and the controlled release of water from the Pongolapoort dam, most residents agreed that it played an important role in their lives. Amongst other it supported agricultural activities (mainly in the form of vegetable gardens), fishing for subsistence and allowing for small scale commercial ventures. Furthermore it enabled them to water their livestock, engage in religious rituals such as baptism, and it provided water for household use. However, participants also expressed concerns in relation to the management of controlled water release onto the floodplain. In all instances of the research (especially phase one and two of the research) a main concern was that the ensuing flooding often washed away vegetable gardens. In some cases, a loss of livestock were reported due to drowning following water release. Some leaders (inclusive of *Indunas*) and residents were concerned that the flooding blocked access roads to schools.

From the outcome it appears that the community currently does not pose any threat to the fish reserves in the floodplain. Though fish is readily consumed, it does not necessarily come from the Ndumo pans and rivers in the area, but from fishing practices further south at the Pongolapoort Dam. Cultural fishing practices, as generally expected from an indigenous knowledge system perspective, appear to be lower than had been anticipated. This further means that cultural fishing practices also pose no immediate threat to the Ndumo area. Thus, with regard to the conservation implications for the area, it can be said that given the sensitivity of the floodplain ecosystem (Umkhanyakude DM, 2012) additional research on fish reserves further south and closer to the Pongolapoort Dam, and the continuous monitoring of the situation, are important to assess and ensure the sustainability of human-fish interactions in the region.

Possibilities of constructively establishing fish farming industries in the Phongola floodplain, as especially suggested for by some leaders in the Jozini Municipal Area, was in fact assessed by Heeg & Breen in 1982 (p. 73). It was then stated that the area is "totally unsuited to aquaculture due to the construction and management of permanent ponds/pans in an area subject to periodic flooding". It was added that the release of enriched or saline water from ponds into pans or the River is undesirable. The fish farming potential within irrigation schemes in the clay-like Rensburg soil area like the Makhathini Flats (adjacent to the floodplain) are said to be suitable for fish culture practicing (Heeg & Breen as well as IDP 2013/14, p. 35). With fish such as the Mozambique tilapia, the catfish and the red-breasted tilapia – able to tolerate water of considerable salinity – makes it possible to utilise irrigation seepage water. By 2014 the difficulties surrounding the seasonal flooding and occasional fish catching activity in pans for fish after flooding was seen as rather having a tourist potential for watching, observing and participating in this irregular seasonal happening in especially summer time.

The findings further revealed that, despite significant challenges such as poverty, poor infrastructure, concerns about education, and an inadequately perceived provision of basic municipal services, members of the Ndumo community exceeded above average levels of psycho-social wellbeing generally. The rural nature of the community, which allows for agricultural practices, probably is the main reason for this status. In addition, there is a tendency to maintain and respect traditional moral values which allows people to feel secure and safe. Other attributes that contribute to the wellbeing of the Ndumo community are their homogeneous cultural identity and their mainly Christian religious orientation. The findings of this study also raise the issue of the impact of communities being primarily governed by

traditional, rather than local government authority. Future research could investigate the specific ways in which psycho-social wellbeing differs across such communities.

The outcomes of this study should be complimentary to recent studies on the Phongolo river and floodplain, with emphasis on the wellbeing of livelihoods associated with, among others, the use of fish as an ecosystem resource.

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9 ANALYSIS OF REGIONAL SCALE RISK IN THE LOWER PHONGOLO RIVER AND FLOODPLAIN USING A BAYESIAN BELIEF NETWORK MODEL

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9.1 Introduction

The Lower Phongolo River, located in northern KwaZulu-Natal (South Africa), supports one of southern Africa's most important floodplain systems. Although relatively small in size (130 km^2) in comparison to other African floodplain systems, this system has a high economic, social and ecological value to local communities (Heeg & Breen, 1982; Jaganyi et al., 2008). Very little is known about this system, particularly information pertaining to the recent development of the area and excessive increase in resource use from the mid-1990s. This study focuses on the area of the Phongolo floodplain downstream of the Pongolapoort Dam that is characterised by the presence of about 90 depressions or floodplain pans that cover an estimated 20% of the surface area of the floodplain (Heeg & Breen, 1994). This combination of riverine and pan ecosystems has resulted in a rich biodiversity that represents a unique ecosystem in southern Africa. The Pongolapoort Dam was constructed between 1963 and 1976 to control floods and provide water for irrigation to approximately 40 000 ha of land adjacent to the floodplain (Breen et al., 1998). It was expected that as irrigated agriculture increased, cropping would decrease and tourism would increase; however, this potential was never realized and only about 3 000 ha of land is currently irrigated, whilst cropping on the floodplain has expanded.

9.1.1 Physical and chemical stressors

The construction of the dam has resulted in a number of hydrological alterations that have had an impact on the inundation of the floodplain pans, i.e. the volume of water delivered downstream of the dam, the rate and the duration of the flows (Heeg & Breen, 1982). In addition, the streamflows from the mid- and upper Phongolo catchment into the dam have also altered since the dam was built and this has been attributed to the construction of the Bivane Dam in 1995 (Jaganyi et al., 2008).

The Lower Phongolo River flows through a malaria-endemic area. Here, the use of DDT for malaria vector control and other insecticides for agriculture can have profound impacts on

bird reproduction. It is therefore not surprising that this region was the focus of intensive studies during the 1980s and 1990s (Ansara-Ross et al., 2012). These studies showed that the levels of total DDT in the blood and eggs of pied kingfishers (*Ceryle rudis*) from the floodplain were approaching levels that were close to and even exceeding levels where reproductive impairment can be expected (Evans & Bouwman, 2000). The levels in fish (i.e. 26-94 µg/g dw), although at the time thought to be safe for fish health and human consumption (Bouwman et al., 1990), will now, with modern knowledge of its endocrine-disrupting activities, be considered as problematic. Recent studies on the bioaccumulation of organochlorines in muscle tissue of tigerfish showed that levels were still elevated with total DDT concentrations reaching 0.5 µg/g wet weight (Wepener et al., 2012).

9.1.2 Relative Risk Model (RRM) as an ecological risk assessment tool to evaluate adverse impacts of multiple stressors

In their study, Lankford et al. (2010) concluded that as a result of both anthropogenic and flow-related impacts the ecosystem services provided by the Phongolo floodplain have undergone significant changes. The interactions between altered flow volumes and durations coupled to other water and environmental quality stressors result in complex levels of ecological organization, which require a holistic, integrated approach that links science, management activities, and environmental policies.

Ecological risk assessment (ERA) methods have been established to characterise and rank threats to aquatic ecosystems in relation to management objectives (Suter, 1993; Murray & Claassen, 1999). The process involves allocation of magnitudes and probabilities to the adverse effects of anthropogenic activities or natural catastrophes referred to as hazards (Suter, 1993). The identification of a hazard, the magnitude of the hazard and the related uncertainty results in the formulation of risk (O'Brien & Wepener, 2012). Risk, therefore, is the probability or likelihood of a prescribed undesired effect occurring and impacting the environment (Suter, 1993). Traditional ERA approaches have primarily addressed the potential risk of a single chemical or a small number of chemicals impacting on a limited number of ecological endpoints (O'Brien & Wepener, 2012). This has limited the application of the ERA methodology in complex ecosystems where numerous use activities or sources and associated stressors affect numerous receptors (Claassen et al., 2001). This led to Landis and Wiegers (1997) developing the Regional-Scale Risk Assessment (RRA) which makes use of the Relative Risk Model (RRM). Wiegers et al. (1998) describe RRA as a

summary of complex interactions and effects of chemical and non-chemical stressors on various ecological endpoints.

A RRA is a form of ERA that is carried out on a spatial scale that considers multiple sources of multiple stressors affecting multiple endpoints where allowance is made for the characteristics of the landscape that may affect the risk estimate (Landis, 2005). O'Brien and Wepener (2012) subsequently developed an ERA approach for application in southern Africa, which incorporates the use of the Relative Risk Model (RRM) and Bayesian Network modelling. Following the initial development, the RRM has been refined into the working method, which has been tried and tested in numerous risk assessments around the world (Thomas, 2003; Hayes & Landis, 2004; Landis & Thomas, 2009; Apitz, 2012). With the opportunity to test the RRM approach through so many case studies, the approach has been criticised (Cook et al., 1999; Cormier et al., 2000), validated, and refined into the working method presented by Landis (2005), Colnar and Landis (2007) and O'Brien and Wepener (2012). This revised approach allows for the evaluation of the relative threats to a range of defined endpoints or management objectives on a spatial scale. The RRM is a regional scale ecological risk assessment tool that has been widely used to evaluate the likelihood of adverse impacts from multiple stressors or disturbances on socio-ecological endpoints (Landis, 2005; O'Brien & Wepener, 2012). The approach involves the characterisation of causal pathways linking the source of potential impacts, the habitat or location of the ecological components of interest, and the potential impacts to those socio-ecological entities (Landis, 2005).

Bayesian network (BN) modelling techniques have recently been incorporated into ecological risk assessments, including RRM case studies (Pollino et al., 2007; Ayre & Landis, 2012; Hines & Landis, 2014). Bayesian networks are transparent, adaptable graphical probability models that incorporate quantitative data and expert judgement to generate risk probabilities where uncertainty is addressed in the conditional probability tables (Ayre & Landis, 2012; Hines & Landis, 2014). This tool is inherently hierarchical and causal which can be used to evaluate the synergistic effects of various disturbances and used for alternative decisions or management options (Ayre & Landis, 2012). In this chapter the ten RRM steps were applied to evaluate the risk of multiple stressors associated with the use of the aquatic resources in the Phongolo floodplain to selected social (subsistence fisheries) and ecological (riparian birds, frogs and fish communities) endpoints.

9.2 Material and methods

9.2.1 Study area

The spatial scope of the BN-RRM selected was the Phongolo River and its associated floodplain pans from below the Pongolapoort Dam, up to the Mozambique border. It extends for approximately 50 km in length with an adjacent floodplain pan system of 130 km^2. There is a considerable body of historical data for this region (Lankford et al., 2010) that demonstrates the importance of the flows required for pan inundation, biodiversity importance and natural resource utilisation by the floodplain communities.

9.2.2 Determination of risk regions

To allow for comparison with the study by Lankford et al. (2010), the risk regions were defined based on the degree of interaction of human communities with the river and associated floodplain pans. The 2011 South African National Census data (Statistics South Africa, 2014) were used to demarcate three different risk regions based on the population numbers of wards adjacent to the river and the floodplain. Risk Region 1 (RR1) extends from the Pongolapoort Dam to the northern edge of the Othobothini ward boundary (north-west bank of the Phongolo River) on the Phongolo River (-27.386289-S, 32.142684-E) and includes all riverine and pan ecosystems associated with the Phongolo River (Figure 9.1). Risk Region 1 includes the Makhonyeni and Mjindi wards and the riverine and pan ecosystem associated with the Phongolo floodplain south to south-east of the Phongolo River and has a lower population than Risk Region 2 (<80 000). Risk Region 2 (RR2) extends from the boundary of RR1 and includes the Nondabuya, Mboza, Bhenindoda, Kwazamazama, Madonela Shemula, Shemula Gata, Lukwane, Kwa-Ndaba, Makhane, Ndumu and Kwamzimna wards up to the boundary of the Ndumo Game Reserve (-26.929993-S; 32.324131-E) (Figure 9.1) and has a population of approximately 200 000. Risk Region 3 (RR3) includes the Phongolo River and associated pans within the Ndumo Reserve (Figure 9.1) which extends from RR2 to the Mozambique border. The lowest population with approximately 1 200 people occurs within Risk Region 3.

9.2.3 Derivation of a BN-RRM for the Phongolo floodplain

The ten established RRM steps were implemented in the study including use of BN modelling techniques (Landis, 2005; Pollino et al., 2007; O'Brien & Wepener, 2012; Ayre & Landis, 2012). During a workshop (July 2013) the members of the different specialist teams, who were responsible for generating the data contained in the preceding chapters, were

tasked to develop conceptual models demonstrating causal pathways that link sources with habitats and management endpoints related to the particular specialist group. The different working groups identified two general management endpoints, i.e. endpoints related to maintenance of biodiversity and utilisation of fish as a natural resource. Eleven different conceptual models were developed. A second series of workshops (July and October 2014) were held during which the conceptual models were reconsidered based on the available information requirements to validate the causal links that were identified. Consensus between the six specialist groups resulted in the reassessment of the causal relationships and finalisation of four conceptual models related to maintenance of fish, amphibian and bird biodiversity and utilisation of fish as a protein source. These conceptual models were formatted into BN structures (Figures 9.3-9.6) and the models were parameterised.

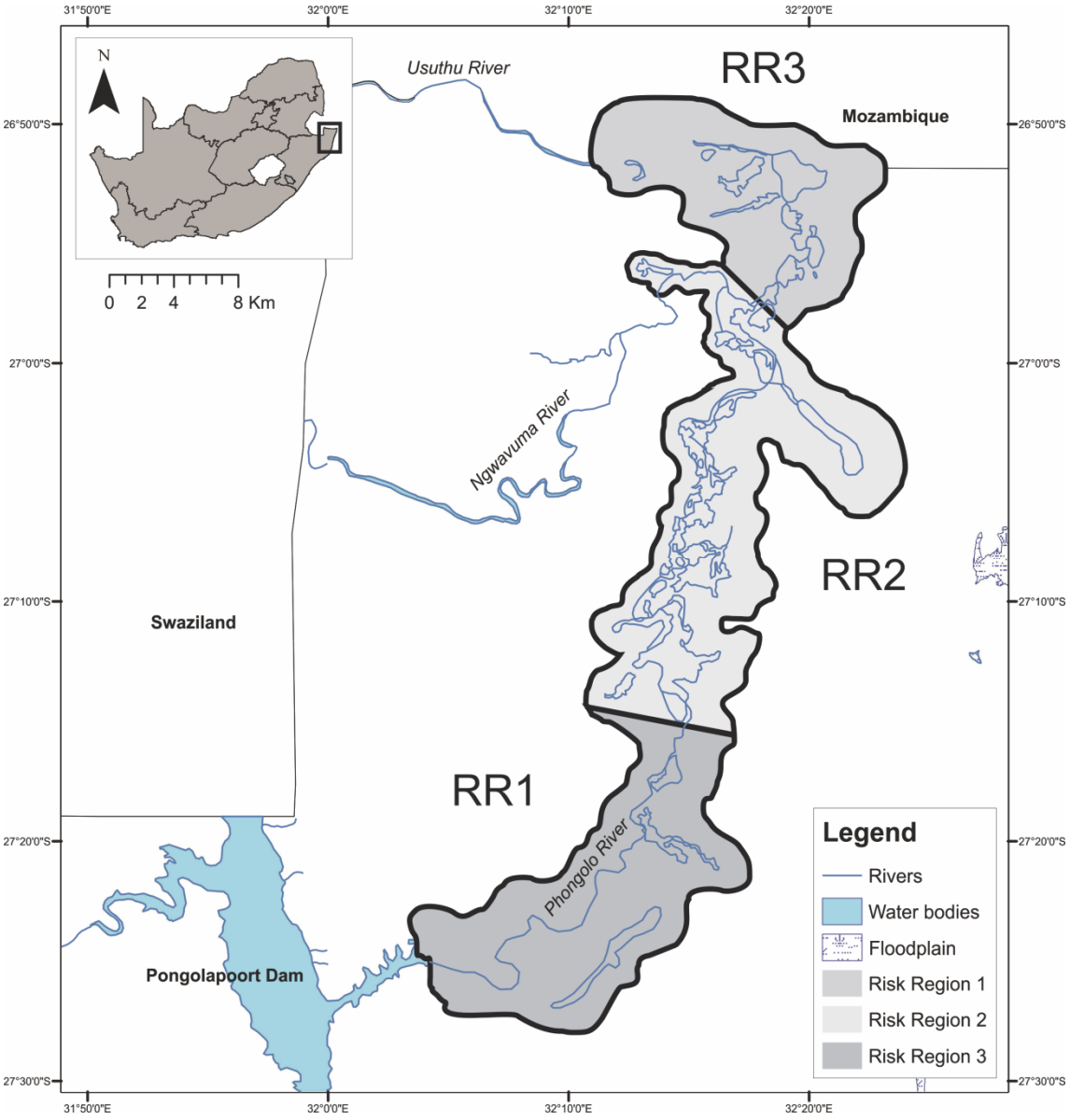


Figure 9.1. Map of the study area including the spatial scope of Risk Regions 1, 2 and 3 considered in the risk assessment of the use of the Phongolo floodplain water resources.

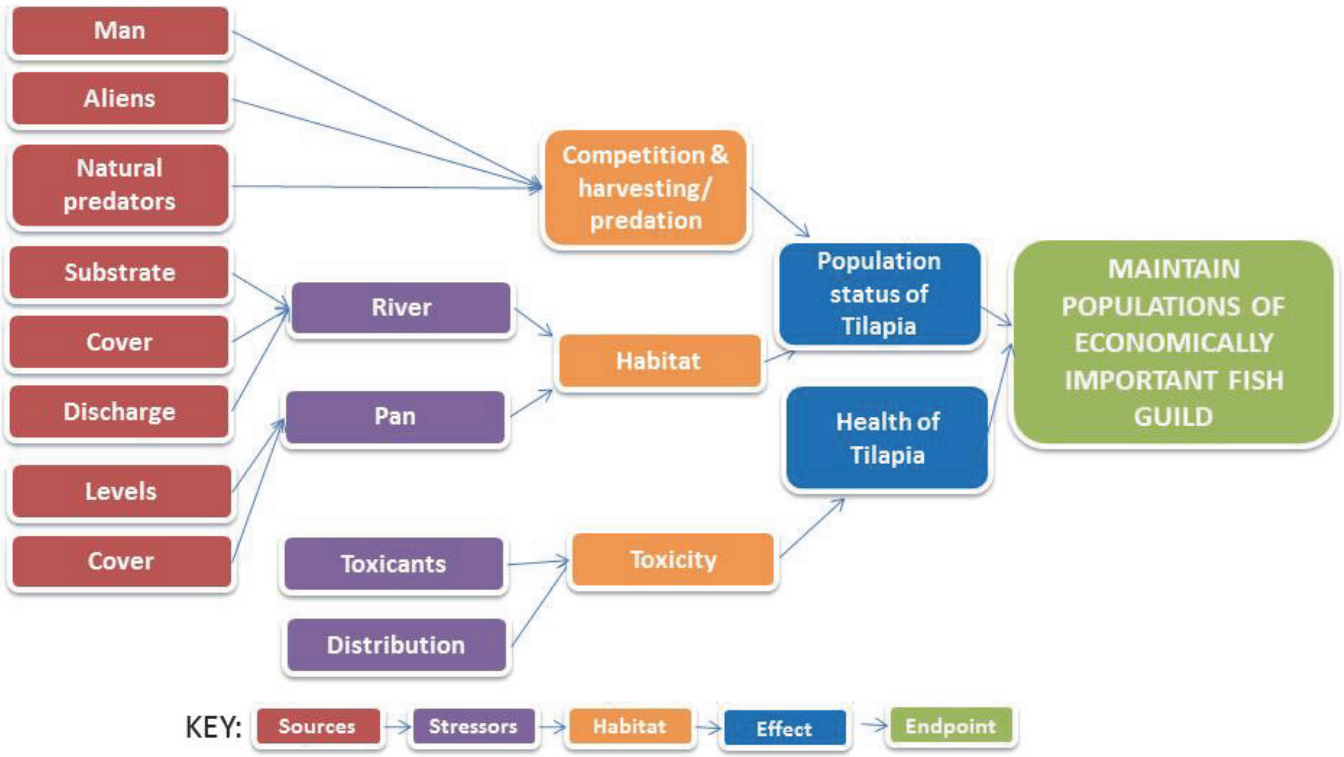


Figure 9.2. An example of one of the 11 conceptual models that was developed to evaluate the relative risk to the Phongolo floodplain. In this instance the causal pathways are presented between sources, stressors and overlap with habitat to induce an effect to the endpoint related to maintaining healthy populations of economically important tilapia.

Rankings were defined for each node based on the particular management goals. Conditional probability tables (CPTs) were created to create the structure of the model. The CPTs provide the insight into causal relationships as they are based on the existing knowledge. Risks were calculated and the model was evaluated for uncertainty and sensitivity using entropy reduction analysis. The models were applied to three different scenarios to evaluate the risk during each condition. The cumulative risk of all endpoints within risk regions or scenario was determined using Monte Carlo simulations.

Conceptual models and BN structure: The conceptual models are not presented, but the BN model structures were directly derived from these conceptual models in which each source, stressor, habitat, effect and endpoints were converted into nature nodes since probability distributions were available. The BN structure consists of tiers of nodes where tier 1 is comprised of sources and stressors, tier 2 represents the habitat node and the last tier comprises of the ecological endpoint. Prior to linking the nodes through causal relationships as defined by the CPTs, a non-dimensional ranking scheme was developed so that effects of the various stressors to the various endpoints could be measured and compared (Landis, 2005). A standardised four-state ranking scheme, commonly used in RRM assessments (Landis & Wiegers 1997; 2005) was applied. Zero or low was used to describe unlikely contributions to the total risk scores to the endpoint, while high was used to describe a high probability that a great risk exists to the particular endpoint. These ranks were assigned a numerical score with no risk = 0, low risk = 2, medium risk = 4 and high risk = 6. Next the distributions are delineated within each node to represent the probability of each of the states. The BN then calculates the scores based on the assigned probability. Prior probabilities of the model variables are then integrated using CPTs, which would then define the posterior probability distributions to calculate the probability of risk to the endpoints (Ayre and Landis, 2012). In this study Netica software (Norsys Software Corp., Vancouver, BC, Canada) was used to conduct the BN network assessment.

The three BN model structures related to maintaining biodiversity were for the maintenance of amphibian biodiversity (Figure 9.3), bird biodiversity (Figure 9.4) and fish biodiversity (Figure 9.5). Since the sources and stressors are the same for maintaining fish biodiversity and providing suitable fish for human consumption, the BNs for these two endpoints were integrated into a single BN (Figure 9.5). The suitability of fish for human consumption was considered from the perspective of the fish being of sufficient quality as well as quantity.

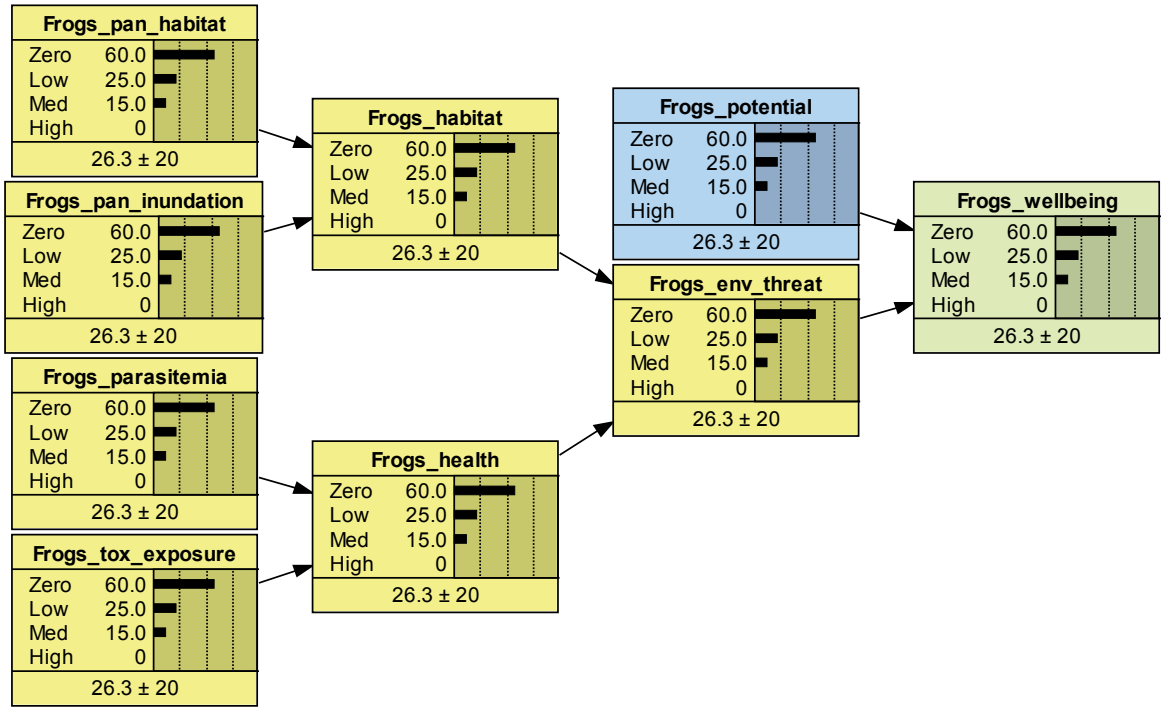


Figure 9.3. Bayesian network belief model representing the causal relationships (arrows) linking the exposure (yellow section) and effects (blue node) components of the risk assessment to the amphibian biodiversity (frog wellbeing) endpoint.

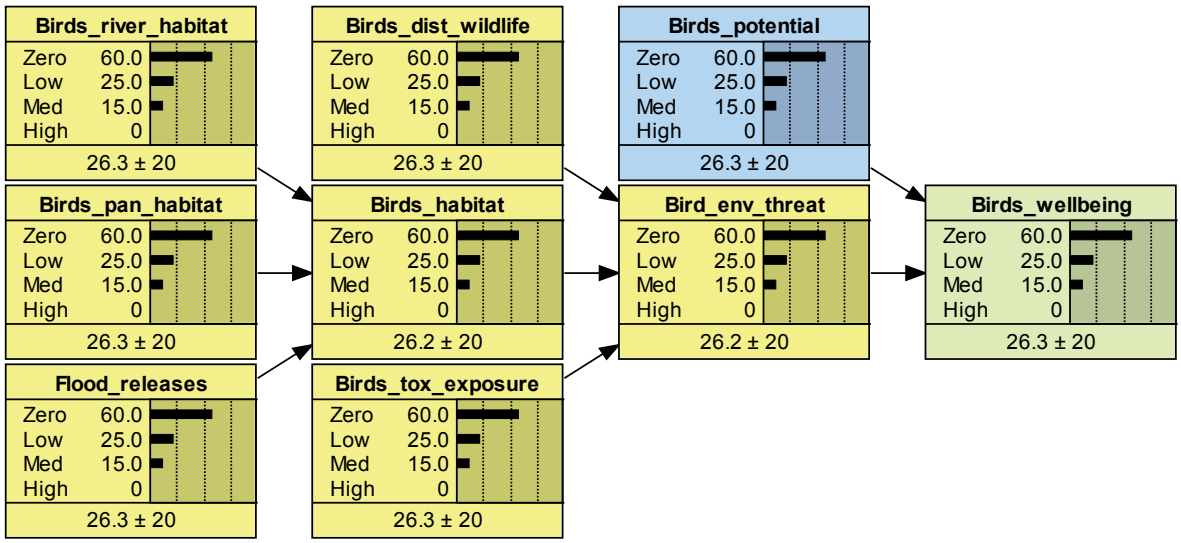


Figure 9.4. Bayesian network belief model representing the causal relationships (arrows) linking the exposure (yellow section) and effects (blue node) components of the risk assessment to the bird biodiversity (bird wellbeing) endpoint.

9.2.4 Model parameterisation

This section describes the decisions and assumptions for each node. The causal relationships are based on existing knowledge using a combination of data gathered from this study, data from the published literature, data from grey literature and expert opinion. Throughout the model the “zero” state rank was used to represent no risk or no threat conditions that would not pose a risk to the endpoint considered. This state often related to the natural/un-impacted and/or ideal state of the variable. The “low” and “moderate” states represent acceptable and concerning states of the nodes in relation to the endpoint. The “high” state was used to represent the variable state in an unacceptable condition where a great likelihood of the endpoint being a risk by the variable considered (Hines & Landis, 2014).

The CPTs defined for the causal relationships for the maintenance of amphibian and bird biodiversity are presented in Tables 9.1 and 9.2 respectively. The CPT for the two endpoints related to fish, i.e. maintenance of fish biodiversity and providing fish fit for human consumption is presented in Figure 9.3.

9.2.5 Model evaluation

After the completion of the BN models and the preliminary analyses, the model’s structure, parameterisation and findings were evaluated by the subject experts. The causal relationships were also compared with the hydrographic approach used to understanding water-reliant livelihoods in the same area (Lankford et al., 2010) as well as endpoints used in previous RRM studies (Wepener et al., 2011).

9.2.6 Sensitivity analysis

The process is completed by conducting a sensitivity analysis of the model and revising the data with new evidence or knowledge (Pollino et al., 2007). The risk calculated may be compared between individual endpoints per risk region or by management scenario, and the cumulative risk of all endpoints within risk regions or management scenarios can be determined using Monte Carlo simulations (Oracle Crystal Ball software, Oregon). This approach was also used to evaluate the effects of uncertainty on risk projections. In general, a sensitivity analysis examines how uncertainty in a model’s output can be attributed to uncertainty in the model’s different input parameters. This is especially important in ERAs because a sensitivity analysis can identify key drivers in the model and the sources of uncertainty that contribute to overall uncertainty in a model’s results. A sensitivity analysis

can lead to recommendations for areas of future monitoring or research (Pollino & Hart, 2008), and the inclusion of additional data into the model can sometimes reduce uncertainty. Sensitivity analysis is paramount in such a model when the aim of the risk assessment is to inform and assist resource managers in their management decisions. According to Nyberg et al. (2006) information derived from directed research and monitoring activities is used to inform decision-making and therefore plays a pivotal role in adaptive management. Sensitivity analyses for discrete variable nodes were calculated in Netica (Norsys Software Corp.) as the degree of entropy reduction. Entropy reduction is the extent to which an input variable influences the response variable, so that the greater the entropy value the greater the degree of influence (Marcot et al., 2006). We used the information gained from the sensitivity analysis for endpoint variables to determine the input parameters that had the greatest influence on risk estimates and the associated uncertainty.

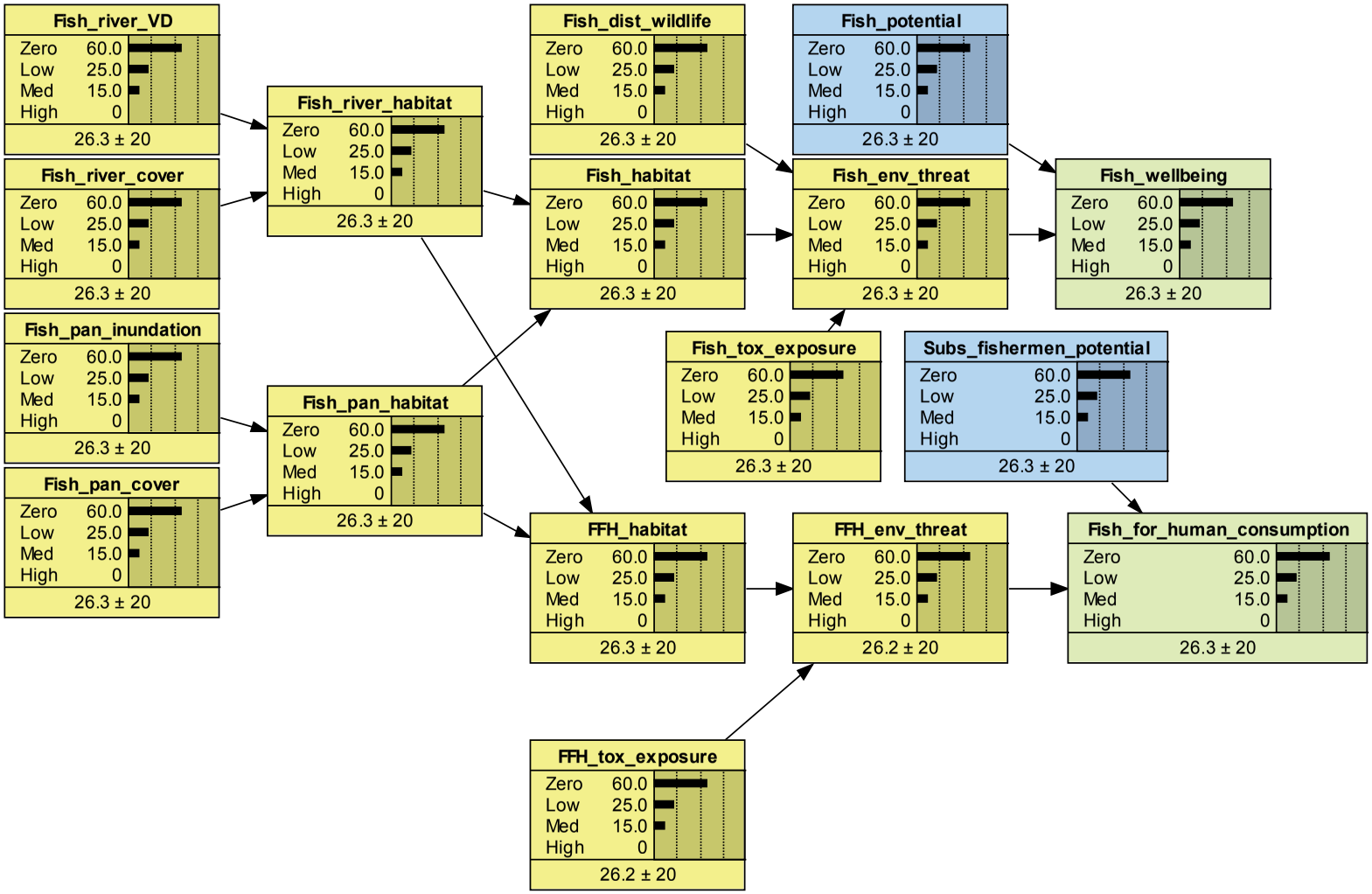


Figure 9.5. Bayesian network belief model representing the causal relationships (arrows) linking the exposure (yellow section) and effects (blue node) components of the risk assessment to the fish biodiversity (fish wellbeing) and subsistence fishery (fish for human consumption) endpoint.

Table 9.1. Summary of the exposure and effect variable (input node) descriptions, justifications, risk input ranks and references for the endpoint related to maintenance of amphibian biodiversity (frog wellbeing).

Parent nodes description (node name)	Rank	Score	Narrative criteria for measure	Numerical criteria (units)	Justification	References
Suitability of pan riparian and instream habitats for frogs (Frogs_pan_habitat)	Zero	25	Well vegetated, grass dominated pans	>95% vegetation cover	This variable considers the availability of riparian vegetation for frogs and fishes in pans. Well vegetated, grass dominated pans are required to maintain communities. The extent of vegetation loss and bank modification was selected as the measure for this variable.	This study
	Low	50	Moderate change to vegetation cover no isolated bank modification	50-95% vegetation cover		
	Moderate	75	Extensive bank modification	5-50% vegetation cover		
	High	100	No vegetation available	<5% vegetation cover		
Suitability of floods required to inundate pans for frogs (Frogs_pan_inundation)	Zero	25	100% of pans inundated	>142 m^3/s	The measure selected to represent the pan inundation variable is average flow (m^3/s). The extent of inundation and duration in the floodplain were considered in this section. Frogs that are mobile have a requirement for pans to be inundated for at least 30 days to complete important life cycle events. Fish, however, migrate from the river into the pans for various life cycle events and potentially return to the river during receding flows. As such the extent of the floods to inundate the pans and the duration of the inundation is of importance to the wellbeing of the local fish communities. No data are available on the duration of inundation of pans. Information that describes the cumulative inundation of pans in the floodplain is available. The duration of the inundation of the pans located in close proximity to the river is considered to be associated with the extent of the inundation. This information was used as the measure for this assessment. Available cumulative percentage inundation data of the pans in the floodplain are linked to the average flow released from the Pongolapoort Dam into the floodplain. Natural breaks (Jenks) were used to divide the data into zero, low, moderate and high categories due to limited data.	Lankford et al., 2010; this study
	Low	50	75% of pans inundated	85-142 m^3/s		
	Moderate	75	50% of pans inundated	72-85 m^3/s		
	High	100	25% of pans inundated	<72 m^3/s		
Threat of prevalence and intensity of parasitemia of frogs (Frogs_parasitemia)	Zero	25	<20% blood cell infection rates	No to low parasitemia	Parasitemia of frogs was selected as an indicator measure of the parasite threats. The measure selected for this variable is blood cell infection rates.	This study
	Low	50	20-80% blood cell infection rates	Minimal parasitemia no changes to communities		
	Moderate	75	81-97% blood cell infection rates	Parasitemia changes frog behaviour		
	High	100	>98%	Parasitemia causes mortality		

Table 9.1. (continued)

Threat of frogs being exposed to toxicants (Frogs_tox_exposure)	Zero	25	None	0 µg/g (wet weight)	This variable considers the threat of DDT to frogs in the study area based on available international toxicity data. Here the threat levels to the European common frog, *Rana temporaria* were applied. The threat of frogs to exposure is dependent on the exposure conditions and age of tadpoles at time of exposure where up to 6% mortality at as low as 3.9 µg/g. The experiments also show highly significant differences in resistance between toads and frogs leading to the assumption that some frog species can possibly be even more sensitive than these values may indicate.	Cooke, 1972; 1979; de Solla et al., 2002
	Low	50	No observable effects / sublethal cellular effects may occur.	>0-2.4 µg/g (wet weight)		
	Moderate	75	Behavioural changes / Developmental changes	2.4-7.5 µg/g (wet weight)		
	High	100	Morphological changes / Mortality	>7.5 µg/g (wet weight)		
Potential for frog diversities to occur in the study area (Frogs_potential)	Zero	25	Low potential for high diversities of frogs to occur	Potential for 5% of species to occur	The potential for frogs to occur in the pans variable was included in the assessment as an effects or receptor variable. The potential percentage of known species to occur in the region considered was used.	
	Low	50	Moderate potential for high diversities of frogs to occur	Potential for 6-50% of species to occur		
	Moderate	75	High potential for high diversities of frogs to occur	Potential for 51-94% of species to occur		
	High	100	Excellent potential for high diversities of frogs to occur	Potential for 95% of species to occur		

Table 9.2. Summary of the exposure and effect variable (input node) descriptions, justifications, risk input ranks and references for the endpoint related to maintenance of bird biodiversity (bird wellbeing).

Parent nodes description (node name)	Rank	Score	Narrative criteria for measure	Numerical criteria (units)	Justification	References
Suitability of riverine riparian habitats for birds (Birds_river_habitat)	Zero	25	Excellent riverine structure for birds	Total vegetation cover >75%, includes high abundance of large trees	Riverine bird communities within the riparian zones of the Phongolo Floodplain are known to respond to changes in the height and percentage cover of trees, shrubs and grasses (Coetzer et al., 2015). The measure selected in this study to evaluate the state of riverine structure for birds included percentage cover and abundance of large trees. High diversities of trees, grasses and dense undergrowth are ideal physical structures for bird communities in the riverine habitats. Reductions in the diversity and abundances of these habitat variables negatively affect bird communities.	This study
	Low	50	Moderate riverine structure for birds, minimal alterations	Total vegetation cover 50% to 75%, includes high abundance of large trees		
	Moderate	75	Limited riverine structure for birds, moderate modifications	Total vegetation cover 20% to 50%, includes trees		
	High	100	Inadequate riverine structure for birds, excessive modifications	Total vegetation cover >20%, no trees		
Disturbance of birds by local human communities (Birds_dist_wildlife)	Zero	25	No disturbance to wildlife	Zero people	This variable allows for the threat of human activities associated with population sizes of local communities disturbing bird and fishes in the local river and pan ecosystems. The extent of the potential disturbance to wildlife was evaluated here. Available population information data were used.	Stats SA, 2011; this study
	Low	50	Low disturbance to wildlife	1-100		
	Moderate	75	Moderate disturbance to wildlife	101-5 000		
	High	100	High disturbance to wildlife	>5 000		
Disturbance of fish by local human communities (Fish_dist_wildlife)	Zero	25	No disturbance to wildlife	Zero people		
	Low	50	Low disturbance to wildlife	1-1 000		
	Moderate	75	Moderate disturbance to wildlife	1 001-10 000		
	High	100	High disturbance to wildlife	>10 000		

Table 9.2. (continued)

Suitability of pan riparian habitats for birds (Birds_pan_habitat)	Zero	25	Excellent pan structure for birds	Total vegetation cover >75%, consisting of grasses, shrubs and trees.	Pan bird communities within the riparian zones of the Phongolo floodplain are known to respond to changes in the percentage cover of grass, shrub and tree habitats. The measure selected in this study to evaluate the state of pan structure for birds included percentage cover of grasses, shrubs and trees. High cover percentages are ideal physical structures for bird communities in the pan habitats. Reductions in the diversity and abundances of these habitat variables negatively affect bird communities.	This study
	Low	50	Moderate pan structure for birds, minimal alterations	Total vegetation cover, 50% to 75%, consisting of grasses, shrubs and trees.		
	Moderate	75	Limited pan structure for birds, moderate modifications	Total vegetation cover, 20% to 50%, consisting of grasses and shrubs.		
	High	100	Inadequate pan structure for birds, excessive modifications	Total vegetation cover <20%.		
Suitability of floods required to inundate floodplain habitats for birds (Flood_releases)	Zero	25	>50% of pans inundated for >30 days.	>365 m^3/s	This variable is based on the flows required to inundate floodplains to maintain a high diversity and abundance of riparian habitat for birds. Although highly mobile, the abundance of riparian habitat associated with pans is considered to be a critical driver of the bird community wellbeing.	Lankford et al., 2010
	Low	50	25-50% of pans inundated for >30 days	100-365 m^3/s		
	Moderate	75	25-1% of pans inundated for >30 days.	72-100 m^3/s		
	High	100	Pans inundated for <30 days	<72 m^3/s		
Threat of birds being exposed to toxicants (Birds_tox_exposure)	Zero	25	None	0 µg/g (ww)	Risk equivalent regarded in this instance is the equivalent habitat size loss, of the sparrowhawk population caused by the chemical exposure. The horizontal axis is for the DDE concentration in eggs (mg/kg or µg/g); the vertical axis represents the equivalent loss of carrying capacity that causes the same reduction in the mean extinction time as the exposure to the concentration of DDE in the eggs. For the purposes of this assessment only the curve for K = 100 (the number of females) was considered (grey solid line). The rationale for this being that most of the riparian species do not have breeding female numbers greater than 100.	Nakamaru et al., 2003
	Low	50	Less than 5% loss in carrying capacity	>0-3 µg/g (ww)		
	Moderate	75	5-30% loss in carrying capacity	3-7 µg/g (ww)		
	High	100	> 30% loss in carrying capacity	> 7 µg/g (ww)		
Potential for bird diversities to occur in the study area (Birds_potential)	Zero	25	Low potential for high diversities of birds to occur	Potential for 5% of species to occur	The potential for birds to occur in the riparian zones of the pans and rivers was included in the assessment as an effects or receptor variable. The potential percentage of known species to occur in the region considered was used.	
	Low	50	Moderate potential for high diversities of birds to occur	Potential for 6-50% of species to occur		
	Moderate	75	High potential for high diversities of birds to occur	Potential for 51-94% of species to occur		
	High	100	Excellent potential for high diversities of birds to occur	Potential for 95% of species to occur		

Table 9.3. Summary of the exposure and effect variable (input node) descriptions, justifications, risk input ranks and references for the endpoints related to maintenance of fish biodiversity (fish wellbeing) and fish suitable for human consumption.

Parent nodes description (node name)	Rank	Score	Narrative criteria for measure	Numerical criteria (units)	Justification	References
Suitability of riverine instream velocity-depth (VD) profiles for fish (Fish_river_VD)	Zero	25	Ideal diversity/abundance of biotopes	FRAI VD Metric Score: <5	The abundance and diversity of velocity-depth profiles of riverine ecosystems are well known to be important components of the habitat requirements of fishes. In this study, very little information is available to relate the flows in the Phongolo River to velocity depth profiles which can then be related to habitat requirements of local fish communities. Qualitative evaluations of the available velocity depth profiles have however been carried out through the extensive application of the Fish Responses Assessment Index. These rating were considered to be suitable to use measures of velocity depth state for fishes in the study area.	Kleynhans, 2007; this study
	Low	50	Diversity/abundance of biotopes suitable for >90% of fishes	FRAI VD Metric Score: 5 to 25		
	Moderate	75	Diversity/abundance of biotopes suitable for 75-80% of fishes	FRAI VD Metric Score: 26 to 50		
	High	100	Biotopes limited, unsuitable >35% of fishes	FRAI VD Metric Score: >50		
Suitability of riverine cover feature profiles for fish (Fish_river_cover)	Zero	25	Excellent cover	FRAI Cover Metric Score: <5	The availability of vertical cover is a key environmental variable which affects the suitability of instream habitats for fish. This variable is particularly associated with maintenance habitat and associated recruitment of juvenile fishes and maintenance of fish refugia. Qualitative evaluations of the suitability of cover feature profiles are available through the application of the Fish Response Assessment Index (FRAI) in the study area. These ratings were considered to be suitable to use as measures of velocity depth state for fishes in the study area.	Kleynhans, 2007; this study
	Low	50	Moderate cover, whole channel inundated	FRAI Cover Metric Score: 5 to 25		
	Moderate	75	Limited vertical cover from overhanging vegetation only	FRAI Cover Metric Score: 26 to 50		
	High	100	Threshold for no cover	FRAI Cover Metric Score: >50		
Suitability of floods required to inundate pans for fish (Fish_pan_inundation)	Zero	25	100% of pans inundated	>142 m^3/s	The measure selected to represent the pan inundation variable is average flow (m^3/s). The extent of inundation and duration in the floodplain were considered in this section. Frogs that are mobile have a requirement for pans to be inundated for at least 30 days to complete important life cycle events. Fish, however, migrate from the river into the pans for various life-cycle events and potentially return to the river during receding flows. As such the extent of the floods to inundate the pans and the duration of the inundation is of importance to the wellbeing of the local fish communities. No data are available on the duration of inundation of pans. Information that describes the cumulative inundation of pans in the floodplain is available. The duration of the inundation of the pans located in close proximity to the river is considered to be associated with the extent of the inundation. This information was used as the measure for this assessment. Available cumulative percentage inundation data of the pans in the floodplain are linked to the average flow released from the Pongolapoort Dam into the floodplain. Natural breaks (Jenks) were used to divide the data into zero, low, moderate and high categories due to limited data.	Lankford et al., 2010; this study
	Low	50	75% of pans inundated	85-142 m^3/s		
	Moderate	75	50% of pans inundated	72-85 m^3/s		
	High	100	25% of pans inundated	<72 m^3/s		

Table 9.3. (continued)

Suitability of pan cover feature profiles for fish (Fish_pan_cover)	Zero	25	Well vegetated, grass dominated pans	>95% vegetation cover	This variable considers the availability of riparian vegetation for frogs and fishes in pans. Well vegetated, grass dominated pans are required to maintain communities. The extent of vegetation loss and bank modification was selected as the measure for this variable.	This study
	Low	50	Moderate change to vegetation cover; no isolated bank modification	50-95% vegetation cover		
	Moderate	75	Extensive bank modification	5-50% vegetation cover		
	High	100	No vegetation available	<5% vegetation cover		
Threat of fish being exposed to toxicants (Fish_tox_exposure)	Zero	25	None	0 µg/g (wet weight)	The fish in the study area are known to be exposed to DDT which was considered in the study. The threat assessment of DDT to fish in the study area is based on available lowest low effect residue (LER) from available compositional data and applicable for multiple species. The lethality values used were based on Lake trout at residues as low as 0.29 µg/g (wet weight), but treatment was with DDE and not with technical or p,p'-DDT.	Beckvar et al., 2005
	Low	50	No observable effects but sublethal effects at cellular level may occur	>0-0.07 µg/g (wet weight)		
	Moderate	75	Behavioural changes	0.07-0.55 µg/g (wet weight)		
	High	100	Mortality	>0.55 µg/g (wet weight)		
Potential for fish diversities to occur in the study area (Fish_potential)	Zero	25	Low potential for high diversities of fishes to occur	Potential for 5% of species to occur	The potential for fish to occur in the river and its associated pans variable was included in the assessment as an effects or receptor variable. The potential percentage of known species to occur in the region considered was used.	
	Low	50	Moderate potential for high diversities of fishes to occur	Potential for 6-50% of species to occur		
	Moderate	75	High potential for high diversities of fishes to occur	Potential for 51-94% of species to occur		
	High	100	Excellent potential for high diversities of fishes to occur	Potential for 95% of species to occur		
Threat of subsistence fishermen being exposed to toxicants by consuming contaminated fish (FFH_tox_exposure)	Zero	25	No risk due to consumption of DDT contaminated fish	0	The potential for fish contaminated with DDT was considered in the study. The measure selected to represent the threat of DDT exposure to human health in contaminated fish includes DDT concentrations in fish tissues. Consumption of food databases have been established to provide the necessary information for assessing the health risks associated with consumption of contaminated food. The hazard ratios were calculated using the average daily exposure and the benchmark concentration. The average daily exposure was determined by multiplying the contaminant concentration by fish consumption. In this study the daily fish consumption was calculated based on the data generated through the social survey on human fish interactions in the Ndumo area.	Jiang et al., 2005
	Low	50	Low non-cancer risk due to consumption of DDT-contaminated fish	Both 50^{th} and 95^{th} MEC > 3.5		
	Moderate	75	Moderate cancer risk due to consumption of DDT-contaminated fish	95^{th} MEC > 3.5		
	High	100	High cancer risk due to consumption of DDT-contaminated fish	Both 50^{th} and 95^{th} MEC > 3.5		

Table 9.3 (continued)

Potential for subsistence fishing to occur in the study area (FFH_fishermen_potential)	Zero	25	No subsistence fishing	No subsistence fishermen	The potential for subsistence fishing to occur in the river and its associated pans variable was included in the assessment as an effects or receptor variable. The potential percentage of known species to occur in the region considered was used.	
	Low	50	Subsistence fishing limited	0-500 subsistence fishermen		
	Moderate	75	Subsistence fishing moderate	500-5 000 subsistence fishermen		
	High	100	Subsistence fishing high	>5 000 subsistence fishermen		

9.3 Resource use management scenarios

A range of water resource use scenarios were considered for calibration and sensitivity evaluation of the BN-RRM model. Three different socio-ecological scenarios related to alternative management options for the Phongolo floodplain were considered (Table). These scenarios were based on the scenarios selected by Lankford et al. (2010).

Table 9.4. Summary of the water resource use scenarios considered in the study.

Scenario name	Description
Scenario 1 (present state)	**Present state scenario:** This scenario is based on actual, available data from field surveys, reviews of recent literature and community interviews, etc., that were used to establish present day (present state) variable distributions for the risk assessment.
Scenario 2 (natural pre-1900 condition)	**Pre-1900 state scenario:** This scenario has been included in the study primarily to test the response of the risk assessment model to represent pre-modern anthropogenic impact conditions which were known to occur in the study area. This scenario has been developed to allow for comparisons between these pre-anthropogenic impact conditions, current conditions and other scenarios.
Scenario 3 (desired condition)	**Present-day desired scenario:** This scenario represents a theoretical best attainable state with existing sources and stressors and the implementation of existing local, regional and national conservation and resource use legislation. This scenario was also used to test the sensitivity of the risk model and the criteria for the zero to high risk ranking scheme established for the study.

9.3.1 Present state or current scenario

The current scenario is based on the parameters measured during the surveys conducted between 2012 and 2014. According to Lankford et al. (2010) the current conditions relating to flood releases and the associated effect on the floodplain services are that governance structures are variable and not always effective in optimising the flood releases. The flood regime is unnatural with a single release in the spring. This release seems to be governed by the demand for water by irrigated agriculture, which has become increasingly commercial. The growing human population in the area has placed pressure on the floodplain. This has resulted in encroachment of agriculture into previously vulnerable areas, which in turn has resulted in large-scale changes to primary producers, e.g. distribution and abundance of sedges and changes to secondary producers, e.g. fish production. There has also been a noticeable change in the cultural use of the river and floodplain pans.

9.3.2 Natural or historical scenario

In order to place the current and future scenarios into context, it is useful to consider what may have been regarded as the natural condition. According to Lankford et al. (2010) this would have been at a time prior to any recorded history and before any developments took place. It can be assumed that during this period communities lived in harmony with the natural ecosystem and their use of the resources was on a subsistence basis for an extended period of time. During a workshop conducted by Lankford et al. (2010) stakeholders were of the opinion that in historical times the Phongolo floodplain was characterised by no formal governance or interference by society. Natural flood events would have flooded most of the pans each year resulting in large diversity of ecosystem services. The subsistence society would have lived in harmony with the natural flooding and would have learnt to cope with the unpredictable nature of the floods.

9.3.3 Ideal or desired scenario

This scenario involves the implementation of well constituted and cooperative governance systems that when applied will ensure that there is a balance between the diverse land and resource use activities on and off the floodplain. The land use should be diverse (i.e. a mixture of subsistence and commercial agriculture) but close control will ensure maintenance of the floodplain, while maintaining and conserving the floodplain ecosystem and the attendant ecosystem services. According to Lankford et al. (2010), the local communities were of the opinion that measures should be put in place to maintain the riparian zones, prevent erosion by removing cattle from the land and prevent unsustainable reed harvesting. Agricultural activities should be timed to coincide with the planned flood releases.

9.4 Results and discussion

The output of the BN-RRM model has two components with the first being a numeric score, namely the average and standard deviation of the distributions. These numeric values were used as inputs to derive graphical representations of the relative risk outcomes to endpoints for the three scenarios (Figure 9.6A-F and Figure 9.7A-C).

9.4.1 Present state scenario

The distribution of risk to the maintenance of amphibian diversity in Risk Region 1 is most likely to occur in a low risk state, which suggests that there is a low risk of the endpoint not

being achieved. There is, however, a 20% to 35% possibility that this endpoint may occur in a moderate risk state, as well as a 45% to 60% likelihood that the risk to the bird and fish biodiversity as well as maintenance of subsistence fisheries endpoints would occur in a moderate risk state in Risk Regions 1 and 2.

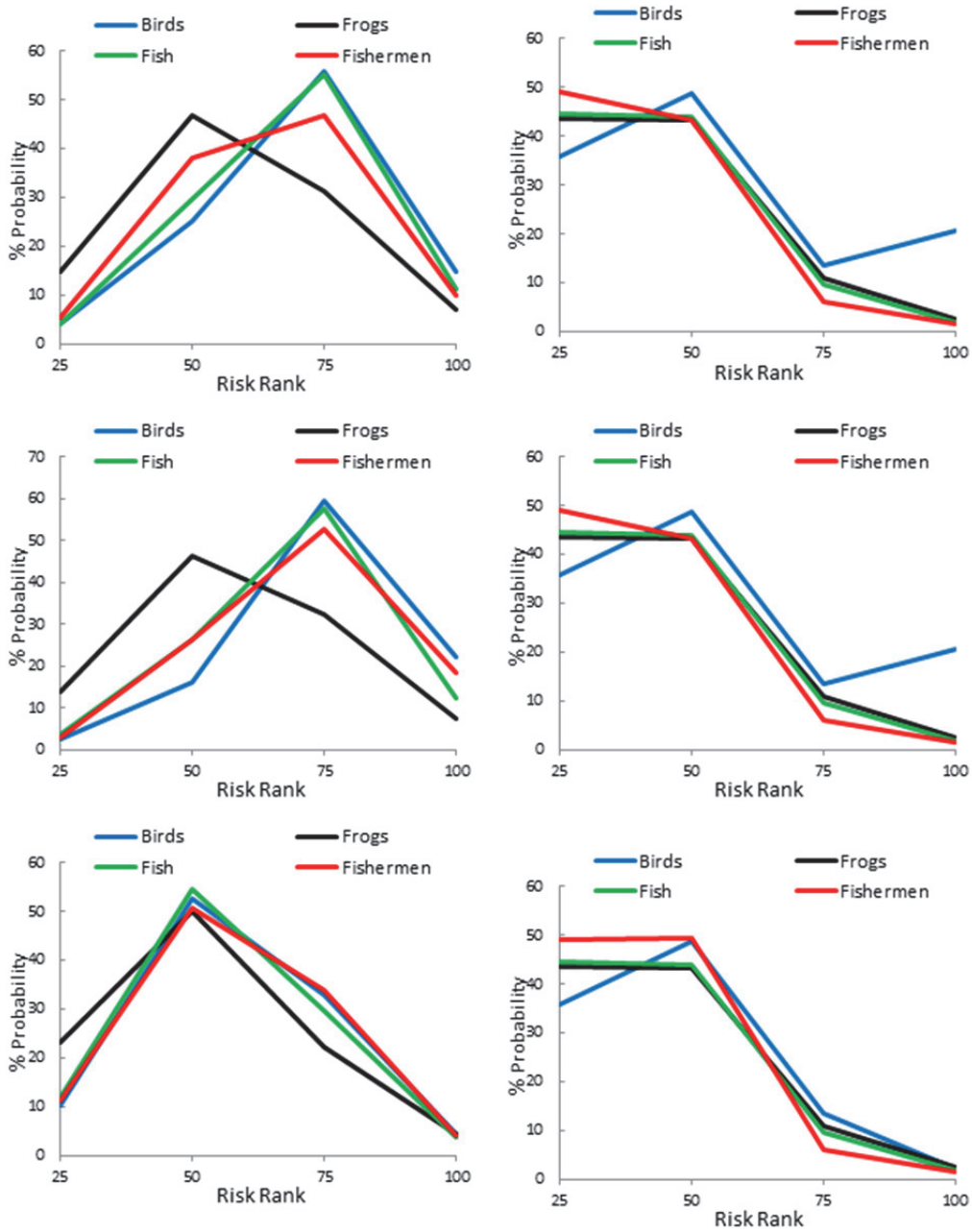


Figure 9.6. Relative risk outcome distributions in each of the three risk regions for the present state scenario (Scenario 1: RR1A, RR2C and RR3E) and natural (historical) scenario (Scenario 2: RR1B, RR2D and RR3F).

Within Risk Region 3 the probability of risk to biodiversity and subsistence fisheries reduces from the moderate risk in upstream risk regions to a 48% to 55% probability of being in a low risk state.

9.4.2 Natural condition scenario

The outcomes for the natural condition scenario show that the BN-RRM models that were developed are sensitive enough, since even though risk to all endpoints would most probably occur in a zero to low risk state, there is a very small likelihood that moderate risk to all endpoints would occur (Figure 9.6B, D, F). This can be attributed to uncertainty in the state of the input nodes and understanding of how the variables interact, which is expected. Interestingly, it is observed that in Risk Region 1 there is 20% likelihood that the maintenance of bird biodiversity would be in a high risk category, which suggests that there is a sensitive component of the node and this endpoint in this region. This can be addressed with a better understanding of the responses of the riparian bird communities to variety environmental variables in the study area. Findings also indicate that maintenance of frog biodiversity is the most tolerant of the endpoints considered. Although the endpoints for the maintenance of bird and fish biodiversity as well as the subsistence fisheries are similar, the bird biodiversity is relatively more intolerant of the threat of resource use.

9.4.3 Desired state scenario

The desired state assessment shows that the risk to the maintenance of subsistence fisheries endpoint will be reduced to low risk states in Risk Regions 2 and 3 as the wellbeing of these communities is shown to be relatively more important than the ecological endpoints which are provided for primarily in Risk Region 3. Monitoring and management are required to maintain these endpoints in this state. This scenario shows that risk to all endpoints may not occur in a high risk state. In comparison to current state distributions there is a considerable improvement in the state of the habitat, a reduction in contribution of DDT to the risk and the disturbance to wildlife threat (appropriate for ecological endpoints only).

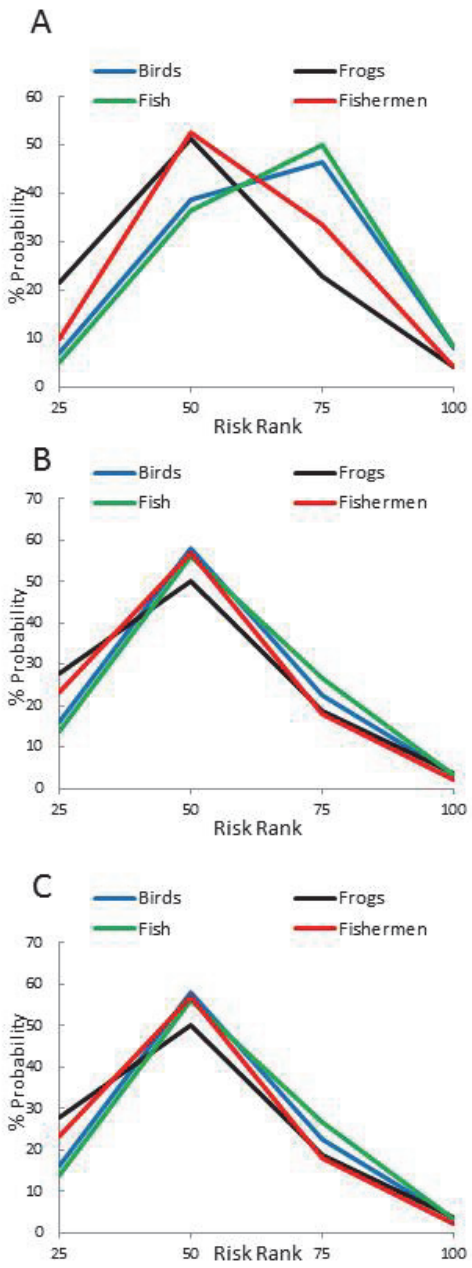


Figure 9.7. Relative risk outcome distributions in each of the three risk regions for the desired state scenario (Scenario 3: RR1A, RR2B and RR3C).

9.4.4 Integrated assessment and sensitivity analysis

The risk distributions for all three scenarios, within the three risk regions considered for this study, were summarised by integrating the four endpoints using Monte Carlo permutations (1 000 iterations/trials). To place the integrated risks posed to the biodiversity and subsistence fisheries into context, the standard A to F classification system that is used in the EcoStatus system was superimposed on the risk distributions (Figure 9.8). This assessment once again provides a clear indication that the BN models are sensitive to changes in the input variables into the nodes.

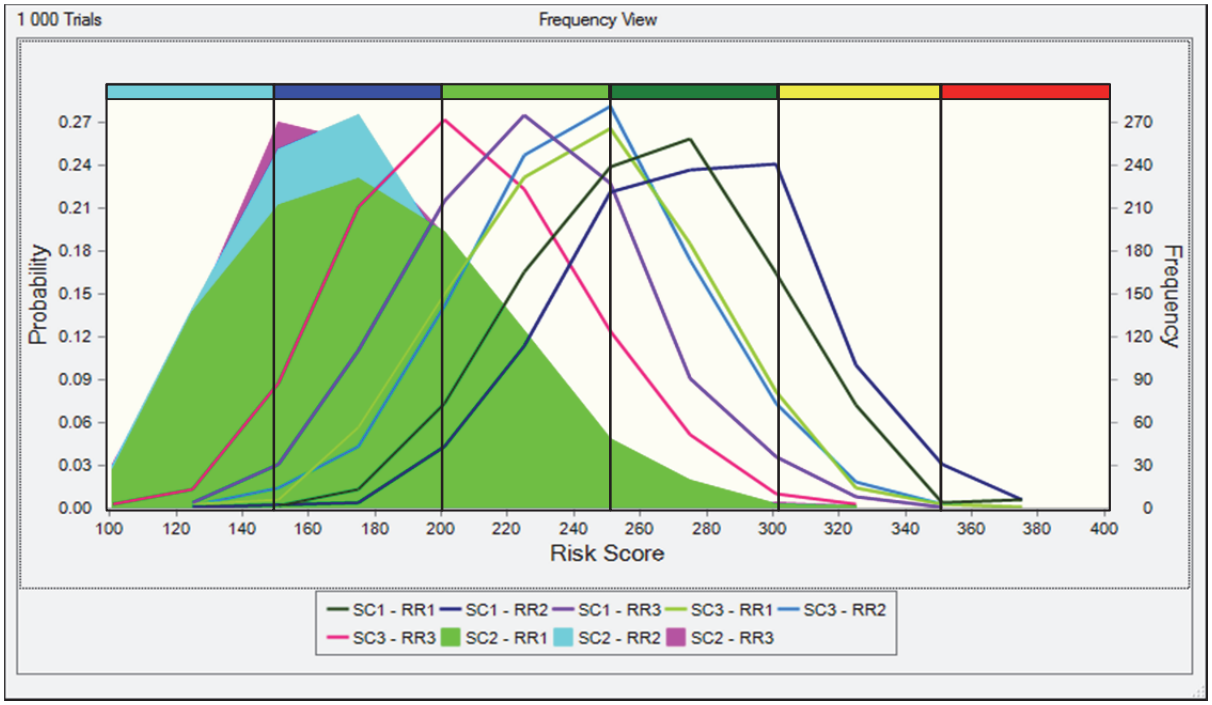


Figure 9.8. Integrated relative risk of all endpoints considered in the study per risk region for present state scenario (Scenario 1 – SC1), natural conditions scenario (Scenario 2 – SC2) and desired state scenario (Scenario 3 – SC3). Six-category risk class from no risk on left (pristine equivalent, EcoStatus class "A") to extreme risk on right (critical modification equivalent, EcoStatus class "F") is superimposed.

9.5 Conclusions

In this chapter it is clearly demonstrated that the BN-RRM model can be applied to identify and inform management actions. Under the current conditions the risk distributions in Risk Regions 1 and 2 indicated that even though there is a small likelihood identified for a moderate risk state for maintenance of frog biodiversity, it may necessitate further

monitoring. However, the greater than 50% likelihood of moderate risk to the endpoints will require management interventions and monitoring.

The reduction from the high likelihood of moderate risk posed to the biodiversity and subsistence fisheries in Risk Regions 1 and 2 to more than 50% likelihood that there would be low risk to these endpoints in Risk Region 3, suggests that the Ndumo Game Reserve is important in providing adequate protection to the upstream regions of the Phongolo floodplain. Although the probability of endpoints being in a high risk (unacceptable state) state is low, ongoing monitoring and regulation should be considered.

One of the strengths of this model is that data gaps can be identified. During the creation of our model, data gaps were identified, particularly for the pan habitat requirements of amphibians and birds. To reduce uncertainty, monitoring information is required and increased confidence in the relationships between variables applicable throughout for what kind of and how much management intervention is required to reduce risk.

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10 CONCLUSIONS AND RECOMMENDATIONS: USE OF THE BN-RRM MODEL AS A RISK ASSESSMENT AND ADAPTIVE MANAGEMENT TOOL FOR THE PHONGOLO RIVER AND FLOODPLAIN

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10.1 Introduction

The Bayesian Network (BN) approach has successfully been applied to evaluate different impacts to forested landscapes in Oregon, USA (Ayer & Landis, 2012), low impact developments in relation to catchment management goals (Hines & Landis, 2013) and assessment of risk posed by parasitic infections caused by whirling disease on natural fish populations (Ayre et al., 2014). During the present study (Chapter 9) we demonstrated how the causal structure of a risk assessment tool such as the relative risk methodology (RRM) can be translated into a graphical BN models. The tiered nodal structure of the BN allowed for the causal linking of sources of stressors, habitats and endpoints of Phongolo River and floodplain. This resulted in successfully achieving Aim 1 of the study.

For the construction of the BN models multiple data types were applied *a priori*. Data types included published literature (Chapter 1), new data generated during the field surveys (Chapters 2-8) and expert knowledge. According to Ayre and Landis (2012) the BN methods are particularly useful to reduce uncertainty because of these different data types through the use of conditional probability tables. As new data become available the BN is easily updated, thereby reducing uncertainty in risk predictions (Howes et al., 2010). The continuous updating of the BN model and the ensuing risk profiles provides a "learning by doing" environment, which is the foundation of the adaptive management process (Nyberg et al., 2006). One application of the BN model is to investigate alternative management scenarios. By altering the source/stressor input variables it is possible to evaluate changes in risk. Furthermore the application of an RRM-based BN is ideal for situations where management strategies are implemented on a spatial scale since the evaluation of these options can then be undertaken by taking regional risk differences into account.

10.2 Management scenarios

To demonstrate the adaptive management application value of the BN that was developed during this study we selected an additional six scenarios to the present (Scenario 1), pre-1900s (Scenario 2) and desired (Scenario 3) state (described in Chapter 9). These scenarios (referred to as Scenario 4 to 9) are presented in Table 10.1.

Table 10.1. Summary of the additional scenarios used to demonstrate the adaptive management application value of the RRM-BN.

Scenario name	Description
Scenario 4 (RR3 protect boundary)	Maintain the boundaries of Ndumo Nature Reserve
Scenario 5 (RR3 community + to RR2)	Increase community pressure on the Ndumo Game Reserve
Scenario 6 (Flow -50%)	Flow release from Pongolapoort Dam reduced by 50%
Scenario 7 (DDT +100%)	DDT bioaccumulation levels in consumed fish increased by 100%
Scenario 8 (Riparian habitat improvement)	Improvement of the state of the riparian habitat
Scenario 9 (Riparian habitat deteriorate	Reduction in the riparian habitat

To evaluate the sensitivity of the RR-BN we exaggerated the conditions represented by the different scenarios. In most instances they could be regarded as worst-case scenarios. The different scenarios can also be related to aspects covered under the aims that were set for the study. The condition probability table (CPT) that allows for the structuring of the risks under the different scenarios is presented in Table 10.2. In Scenario 4 the Ndumo Game Reserve boundary (in RR3) is maintained in its entirety. This requires the removal of all non-conservation communities from the eastern bank of the Phongolo River to represent community pressure as represented under natural conditions (Scenario 2). For Scenario 5 the protective status and boundaries of Ndumo Game Reserve were removed and the community pressure in RR3 was increased to that experienced in RR2 under current conditions (Scenario 1). These two scenarios contribute towards making informed decisions on developing conservation plans for the biota of the study area (**Aim 5**).

Table 10.2. Condition probability table summarising the exposure and effect variable (input node) input distributions for all scenarios considered in the study.

Scenario (name)		Scenario 1 (Present state)			Scenario 2 (Natural <1900)			Scenario 3 (Desired condition)			Scenario 4 (RR3 community -50%)			Scenario 5 (RR3 community +100%)			Scenario 6 (Flow - 50%)			Scenario 7 (DDT +100%)			Scenario 8 (Riparian habitat			Scenario 9 (Riparian habitat		
Node description	**Rank**	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3
Suitability of	Zero	5	5	65	60	60	60	20	10	75	5	5	65	5	5	65	0	0	45	5	5	65	50	50	75	0	0	20
riverine riparian	Low	15	5	30	30	30	30	60	60	20	15	5	30	15	5	30	20	20	40	15	5	30	35	35	20	15	15	20
habitats for birds	Moderate	30	30	5	10	10	10	20	30	5	30	30	5	30	30	5	25	25	10	30	30	5	15	15	5	25	25	40
(Birds_river_habita	High	50	60	0	0	0	0	0	0	0	50	60	0	50	60	0	55	55	5	50	60	0	0	0	0	60	60	20
Distrurbance of	Zero	5	0	10	10	10	10	5	0	10	5	0	0	5	0	0	5	0	10	5	0	10	5	0	10	5	0	10
birds by local	Low	10	5	80	80	75	80	10	5	80	10	5	100	10	5	5	10	5	80	10	5	80	10	5	80	10	5	80
human	Moderate	25	10	10	10	15	10	25	25	10	25	10	0	25	10	10	25	10	10	25	10	10	25	10	10	25	10	10
communities	High	60	85	0	0	0	0	60	70	0	60	85	0	60	85	85	60	85	0	60	85	0	60	85	0	60	85	0
Distrurbance of fish	Zero	0	0	5	55	55	55	0	0	5	0	0	0	0	0	0	0	0	5	0	0	5	0	0	5	0	0	5
by local human	Low	5	1	65	45	45	45	5	5	65	5	1	100	5	1	1	5	1	65	5	1	65	5	1	65	5	1	65
communities	Moderate	20	14	30	0	0	0	20	20	30	20	14	0	20	14	14	20	14	30	20	14	30	20	14	30	20	14	30
(Fish_dist_wildlife)	High	75	85	0	0	0	0	75	75	0	75	85	0	75	85	85	75	85	0	75	85	0	75	85	0	75	85	0
Suitability of pan	Zero	10	5	40	40	40	40	20	20	40	10	5	40	10	5	40	0	0	10	10	5	40	60	55	75	0	0	20
riparian habitats	Low	20	15	30	50	50	50	50	50	50	20	15	30	20	15	30	10	10	30	20	15	30	30	35	20	10	10	35
for birds	Moderate	35	35	30	10	10	10	30	30	10	35	35	30	35	35	30	35	35	30	35	35	30	10	10	5	30	35	30
(Birds_pan_habitat)	High	35	45	0	0	0	0	0	0	0	35	45	0	35	45	0	55	55	30	35	45	0	0	0	0	60	55	15
Suitability of floods	Zero	40	40	40	85	85	85	50	50	50	40	40	40	40	40	40	10	10	10	40	40	40	40	40	40	40	40	40
required to	Low	50	50	50	10	10	10	45	45	45	50	50	50	50	50	50	20	20	20	50	50	50	50	50	50	50	50	50
indundate	Moderate	9	9	9	4	4	4	4	4	4	9	9	9	9	9	9	40	30	40	9	9	9	9	9	9	9	9	9
floodplain habitats	High	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	30	40	30	1	1	1	1	1	1	1	1	1
Threat of birds	Zero	0	0	0	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
being exposed to	Low	50	35	35	0	0	0	80	80	80	50	35	35	50	35	35	50	35	35	5	5	5	50	35	35	50	35	35
toxicants	Moderate	48	60	60	0	0	0	20	20	20	48	60	60	48	60	60	48	60	60	30	30	30	48	60	60	48	60	60
(Birds_tox_exposur	High	2	5	5	0	0	0	0	0	0	2	5	5	2	5	5	2	5	5	65	65	65	2	5	5	2	5	5
Potential for bird	Zero	5	5	0	0	0	0	0	0	0	5	5	0	5	5	0	5	5	0	5	5	0	5	5	0	5	5	0
diversities to occur	Low	20	20	1	1	1	1	20	20	1	20	20	1	20	20	1	20	20	1	20	20	1	20	20	1	20	20	1
in the study area	Moderate	50	40	19	9	9	9	50	50	19	50	40	19	50	40	19	50	40	19	50	40	19	50	40	19	50	40	19
(Birds_potential)	High	25	35	80	90	90	90	30	30	80	25	35	80	25	35	80	25	35	80	25	35	80	25	35	80	25	35	80
Suitability of pan	Zero	10	5	50	70	70	70	10	10	50	10	5	50	10	5	50	5	0	10	10	5	50	50	50	75	0	0	5
riparian and	Low	35	30	45	25	25	25	55	55	45	35	30	45	35	30	45	30	30	40	35	30	45	35	35	15	15	15	15
instream habitats	Moderate	35	40	4	4	4	4	35	35	4	35	40	4	35	40	4	35	35	30	35	40	4	15	15	10	35	35	40
for frogs	High	20	25	1	1	1	1	0	0	1	20	25	1	20	25	1	30	45	20	20	25	1	0	0	0	50	50	40
Suitability of floods	Zero	70	70	70	90	90	90	80	80	80	70	70	70	70	70	70	20	20	30	70	70	70	70	70	70	70	70	70
required to	Low	25	25	25	7	7	7	15	15	15	25	25	25	25	25	25	40	40	40	25	25	25	25	25	25	25	25	25
indundate pans for	Moderate	4	4	4	3	3	3	4	4	4	4	4	4	4	4	4	40	40	40	4	4	4	4	4	4	4	4	4
frogs	High	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	20	20	10	1	1	1	1	1	1	1	1	1
Threat of	Zero	10	5	50	70	70	70	10	10	50	10	5	50	10	5	50	5	0	10	10	5	50	50	50	75	0	0	5
prevalance and	Low	35	30	45	25	25	25	55	55	45	35	30	45	35	30	45	30	30	40	35	30	45	35	35	15	15	15	15
intensity of	Moderate	35	40	4	4	4	4	35	35	4	35	40	4	35	40	4	35	35	30	35	40	4	15	15	10	35	35	40
parasitemia of	High	20	25	1	1	1	1	0	0	1	20	25	1	20	25	1	30	45	20	20	25	1	0	0	0	50	50	40

Table 10.2. (continued)

Scenario (name)		Scenario 1 (Present			Scenario 2 (Natural			Scenario 3 (Desired			Scenario 4 (RR3			Scenario 5 (RR3			Scenario 6 (Flow -			Scenario 7 (DDT			Scenario 8			Scenario 9		
Node description (node name)	**Rank**	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3	RR1	RR2	RR3
Threat of frogs	Zero	0	0	0	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
being exposed to	Low	60	60	60	0	0	0	85	85	85	60	60	60	60	60	60	60	60	60	25	25	25	60	60	60	60	60	60
toxicants	Moderate	22	22	22	0	0	0	15	15	15	22	22	22	22	22	22	22	22	22	45	45	45	22	22	22	22	22	22
(Frogs_tox_exposur	High	18	18	18	0	0	0	0	0	0	18	18	18	18	18	18	18	18	18	30	30	30	18	18	18	18	18	18
Potential for frog	Zero	1	2	1	1	1	1	0	0	0	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1
diversities to occur	Low	4	8	4	4	4	4	5	5	5	4	8	4	4	8	4	4	8	4	4	8	4	4	8	4	4	8	4
in the study area	Moderate	15	20	5	5	5	5	15	15	5	15	20	5	15	20	5	15	20	5	15	20	5	15	20	5	15	20	5
(Frogs_potential)	High	80	70	90	90	90	90	80	80	90	80	70	90	80	70	90	80	70	90	80	70	90	80	70	90	80	70	90
Suitability of	Zero	20	20	20	70	70	70	30	30	30	20	20	20	20	20	20	10	20	30	20	20	20	20	20	20	20	20	20
riverine instream	Low	50	50	50	25	25	25	50	50	50	50	50	50	50	50	50	35	35	30	50	50	50	50	50	50	50	50	50
velocity-depth (VD)	Moderate	20	20	20	5	5	5	20	20	20	20	20	20	20	20	20	35	30	30	20	20	20	20	20	20	20	20	20
profiles for fish	High	10	10	10	0	0	0	0	0	0	10	10	10	10	10	10	20	15	10	10	10	10	10	10	10	10	10	10
Suitability of	Zero	1	1	5	55	55	55	5	5	25	1	1	5	1	1	5	1	1	5	1	1	5	50	25	70	0	0	15
riverine cover	Low	24	9	55	40	40	40	55	55	60	24	9	55	24	9	55	14	14	35	24	9	55	25	50	25	25	25	25
feature profiles for	Moderate	50	55	29	5	5	5	40	40	15	50	55	29	50	55	29	50	50	29	50	55	29	25	25	5	50	25	35
fish	High	25	35	11	0	0	0	0	0	0	25	35	11	25	35	11	35	35	26	25	35	11	0	0	0	25	50	25
Suitability of floods	Zero	60	60	60	90	90	90	80	80	80	60	60	60	60	60	60	1	1	5	60	60	60	60	60	60	60	60	60
required to	Low	25	25	25	7	7	7	15	15	15	25	25	25	25	25	25	14	14	10	25	25	25	25	25	25	25	25	25
indundate pans for	Moderate	14	14	14	3	3	3	4	4	4	14	14	14	14	14	14	35	25	35	14	14	14	14	14	14	14	14	14
fish	High	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	50	60	50	1	1	1	1	1	1	1	1	1
Suitability of pan	Zero	10	5	50	70	70	70	10	10	50	10	5	50	10	5	50	5	0	10	10	5	50	50	25	70	0	0	15
cover feature	Low	35	30	45	25	25	25	55	55	45	35	30	45	35	30	45	30	30	40	35	30	45	25	50	25	25	25	25
profiles for fish	Moderate	35	40	4	4	4	4	35	35	4	35	40	4	35	40	4	35	35	30	35	40	4	25	25	5	50	25	35
(Fish_pan_cover)	High	20	25	1	1	1	1	0	0	1	20	25	1	20	25	1	30	45	20	20	25	1	0	0	0	25	50	25
Threat of fish being	Zero	0	0	0	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	20	20	20	0	0	0	0	0	0
exposed to	Low	90	90	99	0	0	0	99	99	99	90	90	99	90	90	99	90	90	99	45	45	45	90	90	99	90	90	99
toxicants	Moderate	10	10	1	0	0	0	1	1	1	10	10	1	10	10	1	10	10	1	25	25	25	10	10	1	10	10	1
(Fish_tox_exposure	High	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	0	0	0	0	0	0
Potential for fish	Zero	2	5	1	0	0	0	0	0	0	2	5	1	2	5	1	2	5	1	2	5	1	2	5	1	2	5	1
diversities to occur	Low	8	10	4	0	0	0	5	5	5	8	10	4	8	10	4	8	10	4	8	10	4	8	10	4	8	10	4
in the study area	Moderate	30	35	20	20	20	20	35	35	20	30	35	20	30	35	20	30	35	20	30	35	20	30	35	20	30	35	20
(Fish_potential)	High	60	50	75	80	80	80	60	60	75	60	50	75	60	50	75	60	50	75	60	50	75	60	50	75	60	50	75
Threat of	Zero	0	0	0	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
subsistence	Low	40	40	40	0	0	0	75	75	75	40	40	40	40	40	40	40	40	40	15	15	15	40	40	40	40	40	40
fishermen being	Moderate	45	45	45	0	0	0	25	25	25	45	45	45	45	45	45	45	45	45	40	40	40	45	45	45	45	45	45
exposed to	High	15	15	15	0	0	0	0	0	0	15	15	15	15	15	15	15	15	15	45	45	45	15	15	15	15	15	15
Potential for	Zero	0	0	5	20	20	20	0	0	20	0	0	90	0	0	0	0	0	5	0	0	5	0	0	5	0	0	5
subsistence	Low	10	0	75	60	60	60	10	10	60	10	0	10	10	0	0	10	0	75	10	0	75	10	0	75	10	0	75
fishermen to occur	Moderate	80	5	15	20	20	20	80	80	20	80	5	0	80	5	5	80	5	15	80	5	15	80	5	15	80	5	15
in the study area	High	10	95	5	0	0	0	10	10	0	10	95	0	10	95	95	10	95	5	10	95	5	10	95	5	10	95	5

For Scenario 6 the flow release from the Pongolapoort Dam was reduced by 50% from the current conditions (Scenario 1) and the socio-ecological consequences were evaluated. This entailed both the influence of reduced flow on fish biodiversity in the river and associated floodplain pans as well as the availability of fish for subsistence fisheries. Changes in flow releases have implications for maintenance of biodiversity, conservation planning and utilization of resources by local communities (**Aims 3, 5 and 6**).

For Scenario 7 the risk of DDT to the maintenance of biodiversity of amphibians, birds and fish was considered (**Aim 4**). The DDT bioaccumulation was increased by 100% in relation to the levels recorded under current conditions. Although seemingly excessive these values represent concentrations recorded in fish during the intensive DDT spraying period in the 1980s (Ansara-Ross et al., 2012). In addition the risk to humans consuming the fish with these DDT levels were also evaluated (**Aim 6**). All other model parameters were maintained in current state (Scenario 1) conditions.

Scenarios 8 and 9 evaluated the changing of socio-ecological risk profiles related to altered utilization of riparian habitats associated with the Phongolo River and the associated pans. For Scenario 8 an improvement in the state of the riparian zone (reduction in human-related threat distributions) throughout the study area was considered. Scenario 9 evaluated the risk profile alterations due to increased human-related threats. These scenarios address habitat alteration in relation to maintenance of biodiversity (**Aims 2, 3 and 5**) as well as ensuring sustainable fish populations for human use (**Aim 6**).

10.3 Scenario assessment

As could be expected the protection of the Ndumo Game Reserve boundary (Scenario 4) did not have any effect on the risk distributions in RR1 and RR2 (Figure 10.1 B, D and F). Since these distributions were similar to those obtained for the desired state in Chapter 9 it clearly indicates that the model is calibrated. By protecting the boundary there is a considerable reduction in the risk posed to the ecological endpoints in RR3, reducing the probability of the endpoints being in a moderate risk state from 28% to 35% under current conditions to 18% to 30%. This reduction in risk profile is comparable with desired state scenario (Scenario 3). In this instance a change in the input variable resulted in reaching a desired state, however according to Ayre et al. (2014) BNs could also be used to “back-calculate” what the initial conditions would need to be to reach the desired outcome. The reduction in the risk profile can mostly be attributed to the reduced risk to subsistence fisheries since the pressures on fish populations have been removed through the removal of the communities.

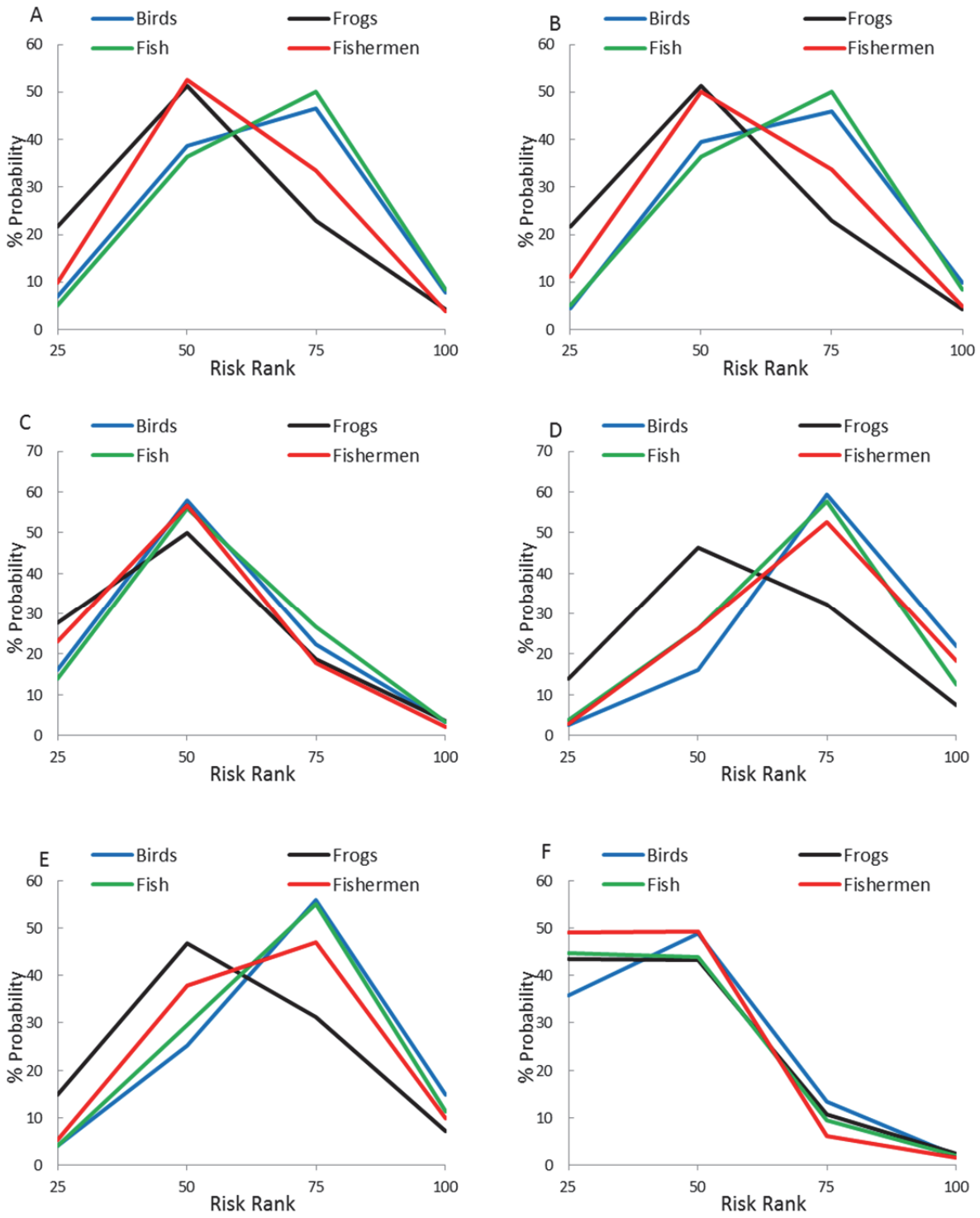


Figure 10.1. Relative risk outcome distributions following protection of the Ndumo Game Reserve boundary (Scenario 4). For comparative purposes the desired state risk distributions are also presented (Scenario 3). Scenario 3: RR1 (A), RR2 (C) and RR3 (E) and Scenario 4: RR1 (B), RR2 (D), RR3 (F).

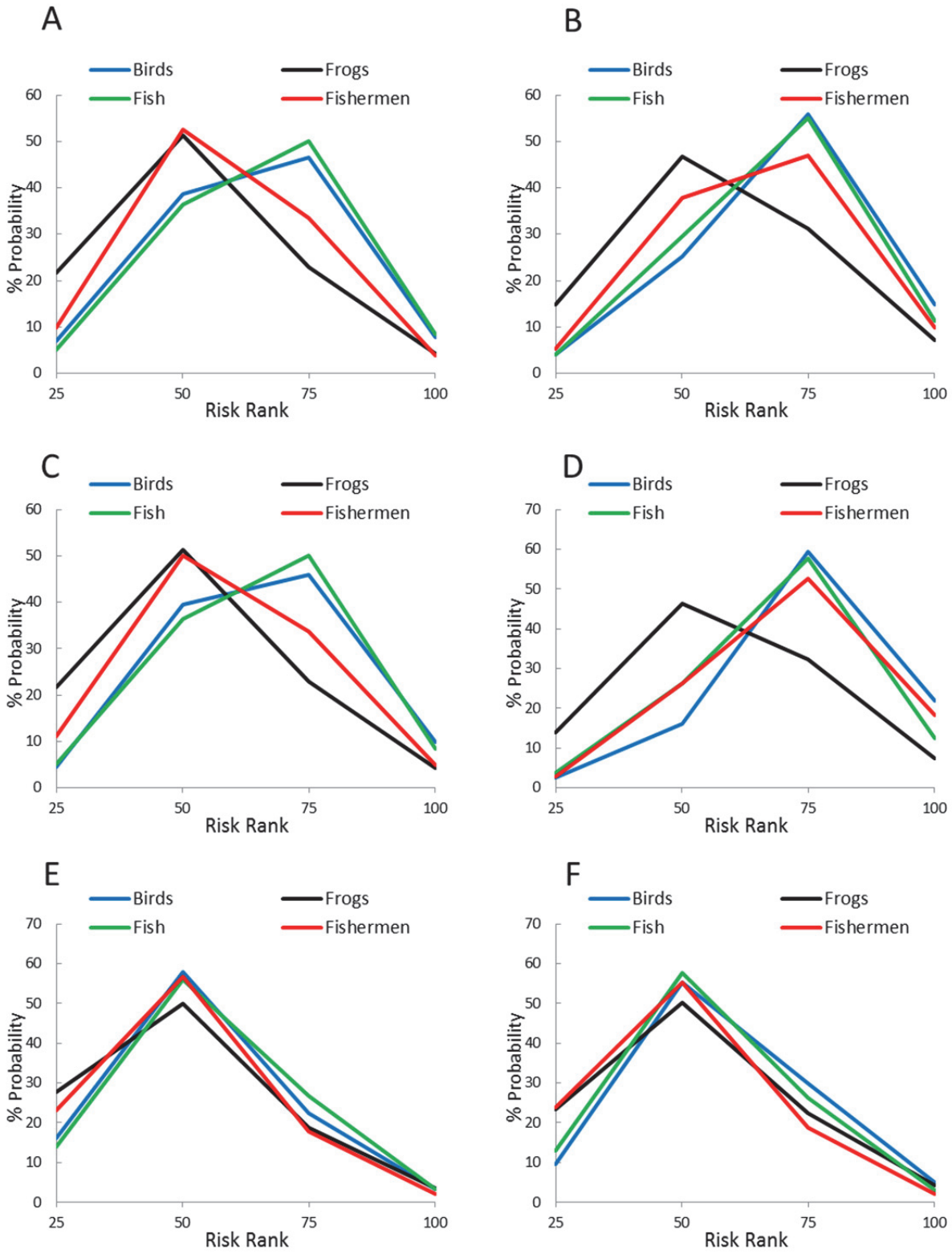


Figure 10.2. Relative risk outcome distributions following the removal of the Ndumo Game Reserve boundary (Scenario 5). For comparative purposes the desired state risk distributions are also presented (Scenario 3). Scenario 3: RR1 (A), RR2 (C) and RR3 (E) and Scenario 5: RR1 (B), RR2 (D), RR3 (F).

In contrast, Scenario 5 risk profiles indicate that should the population pressure in RR3 (Ndumo Game Reserve) increase to those experienced in RR2, the risk to the birds, fish and subsistence fisheries endpoints would all increase to moderate risk states (Figure 10.2 B, D and F). It would therefore remove any refuge function that the Ndumo Game Reserve provided for specifically fish and birds.

The refuge functioning of the Ndumo Game Reserve (RR3) is clearly demonstrated when comparing the risk profile of RR3 with RR1 and RR2 under current conditions. Under Scenario 5 there is a high risk that the sustainable balance between use of resources and protection would not possible. Monitoring and management would be imperative under such a scenario.

Figure 10.3 presents the integrated and cumulative risk posed by Scenario 4 and 5. The EcoStatus risk categories are superimposed above the risk score. The EcoStatus risk categories consist of six risk-classes from no risk (light blue – pristine equivalent, Ecostatus class “A”) to extreme risk (red – critical modification equivalent, Ecostatus class “F”). With a protected boundary the cumulative risk to all endpoints improves to B/C state (desired state) from the current state. In contrast the EcoStatus category will deteriorate to a D class if human pressure is allowed to increase to the extent experienced in RR2. The amplitudes of the risk distributions for Scenarios 4 and 5 are lower than Scenario 1 and greater risk distribution indicating greater uncertainty. This can however be addressed by increasing the data through field monitoring.

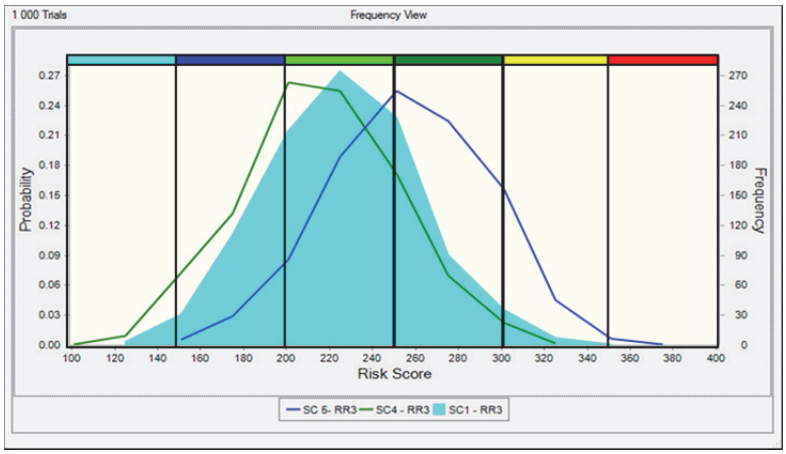


Figure 10.3. Integrated relative risk distributions of all endpoints considered in the study for risk region (RR) 3 for present state scenario (Scenario 1 – SC1), protected boundary scenario (Scenario 4 – SC4) and the increase population pressure in RR3 scenario (Scenario 5 – SC5). Six category risk class from no risk on left (pristine equivalent, Ecostatus class “A”) to extreme risk on right (critical modification equivalent, Ecostatus class “F”) is included.

Risks to all endpoints in all three risk regions will increase in the event of a 50% reduction in flow release from the Pongolapoort Dam (Figure 10.4 B, D and F). The risk is more pronounced in RR1 and RR2 outside of the reserve. Interestingly enough the maintenance of frog biodiversity is now also at risk where it has been the more tolerant endpoint compared to the other endpoints. This is particularly evident in RR3. This is attributed to the floodplain pans playing a more important role as amphibian habitat than the river.

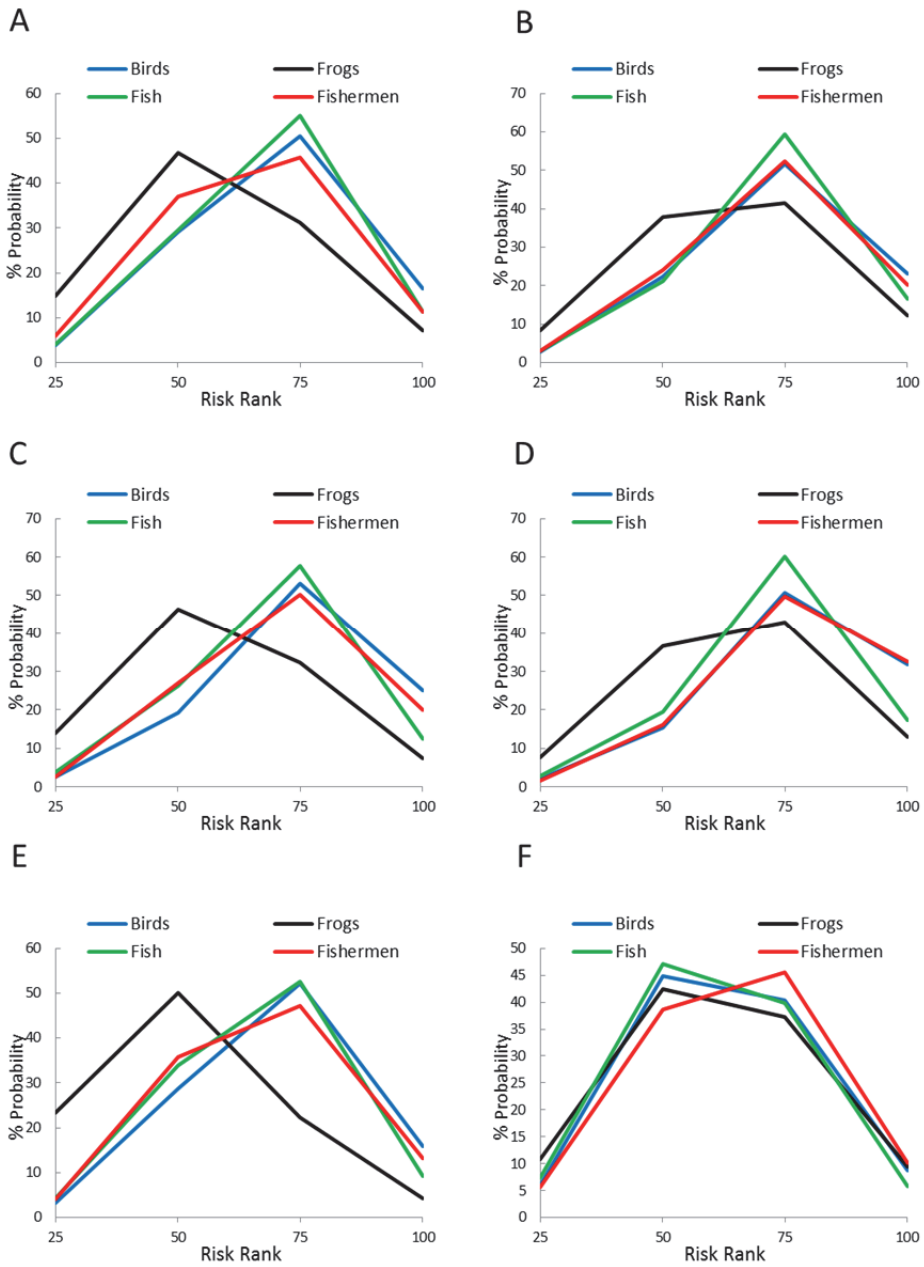


Figure 10.4. Relative risk outcome distributions following a 50% reduction in flow releases from Pongolapoort Dam (Scenario 6). For comparative purposes the risk posed due to an increase in population is provided. Scenario 5: RR1 (A), RR2 (C) and RR3 (E). Scenario 6: RR1 (B), RR2 (D), RR3 (F).

The integrated assessment compared the cumulative risk profiles under current conditions with those that would be experienced should the water release from Pongolapoort Dam be reduced by 50%. As could be expected the EcoStatus categories in all three risk regions reduced as risk increased. This reduction is by one to two risk categories. The higher proportion risk and extended distribution that stretches over two categories indicates that the uncertainty is greater under Scenario 5 than Scenario 1 (Figure 10.5).

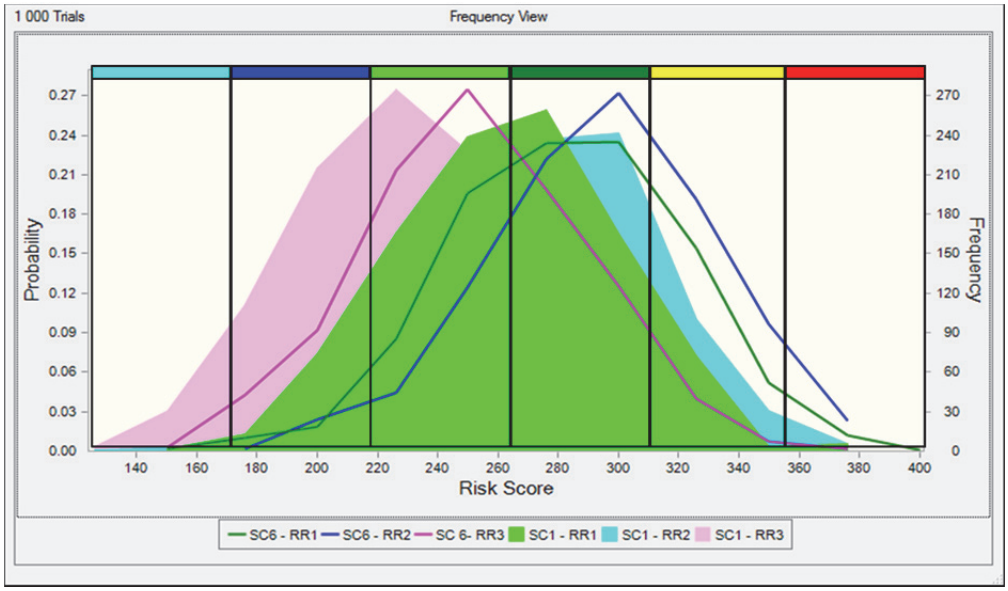


Figure 10.5. Integrated relative risk of all endpoints considered in the study per risk region (RR) under present state conditions (Scenario 1 – SC1) and with a reduction of 50% in flow releases from Pongolapoort Dam (Scenario 6 – SC6).

The over-all risk profiles in response to increasing the DDT levels in amphibians, birds and fish in the three risk regions (Figure 10.6 B, D, F) show similar trends to those recorded for reduced flows (Figure 10.4). Noticeable is the increased risk posed to birds and fish, as well as humans due to consumption of contaminated fish in RR1 and RR2 compared to RR3 (Figure 10.6 B, D, F). The lower risk to amphibian biodiversity can be attributed to lower exposure risk in amphibians since they are not constant contact with water (as is the case with fish) or necessarily feeding exclusively on aquatic prey. Even though the cumulative risk distribution patterns are similar to reduced flows there is a far greater portion of the risk in the E and F categories (Figure 10.7), indicating that chemical exposure poses a greater risk to the well-being of amphibian, bird and fish biodiversity. It stands to reason that risk to humans will be lower if there is no fish to eat due to fisheries population declines in the event of reduced flow, whereas greater chemical loads will increase human health risks.

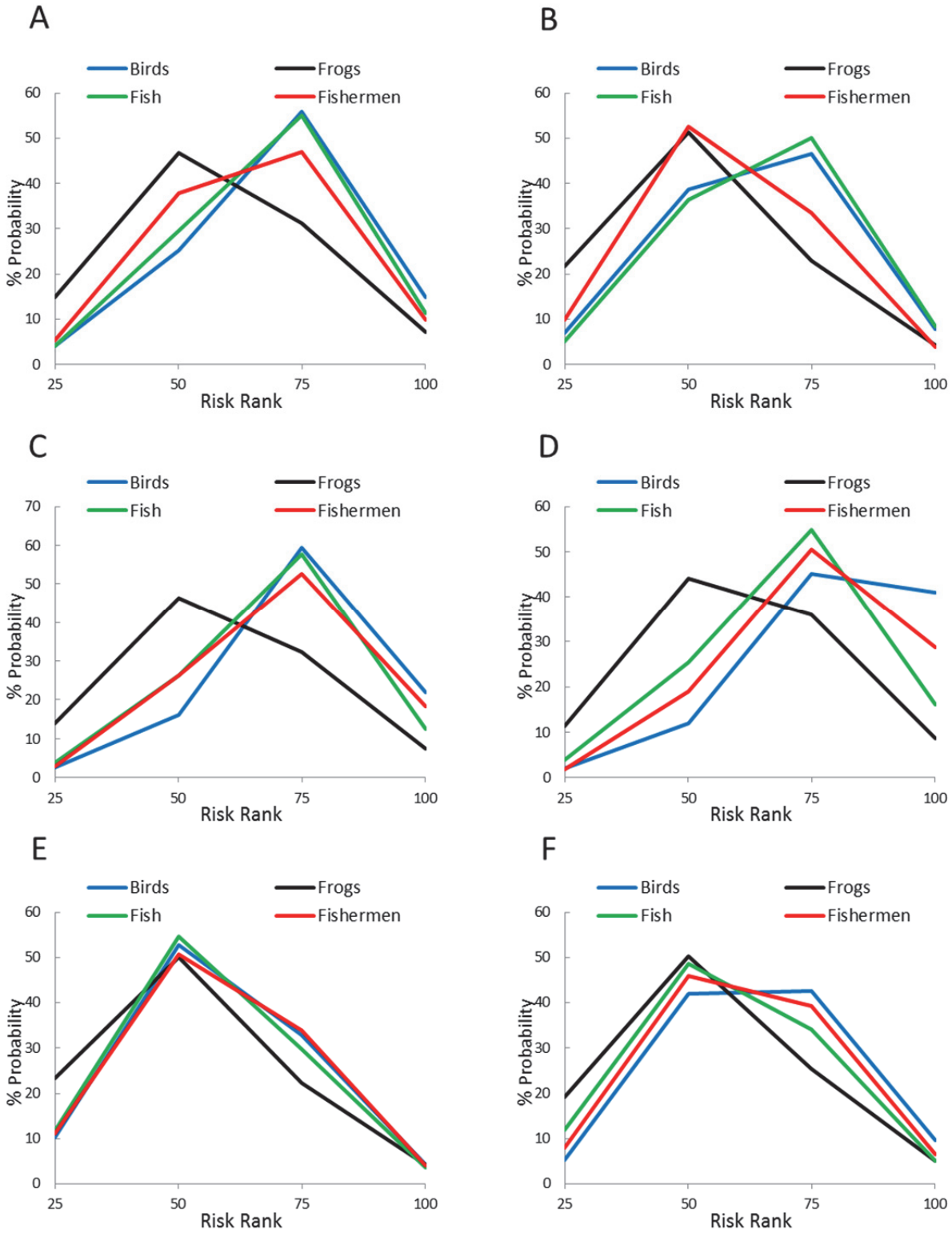


Figure 10.6. Relative risk outcome distributions following a 100% increase in DDT bioaccumulation in amphibians, birds and fish (Scenario 7) in RR1 (B), RR2 (D), RR3 (F). For comparative purposes the risk posed by DDT under current conditions (Scenario 1) is provided.

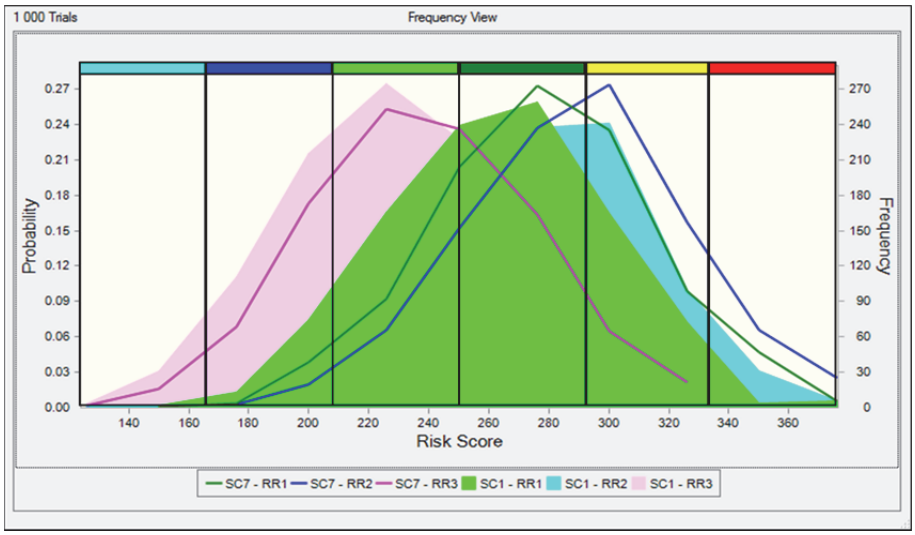


Figure 10.7. Integrated relative risk of all endpoints considered in the study per risk region (RR) for present state scenario (Scenario 1 – SC1) and increase DDT loads by 100% scenario (Scenario 7 – SC7).

Scenarios 8 and 9 involve the influence that alterations to the riparian habitat would have on the risk distributions for the endpoints selected for this study. By rehabilitating riparian zones (Scenario 8) there is a moderate reduction in risk to all endpoints with amphibian diversity displaying the most reduced risk (Figure 10.8 A, C and E). By reducing the riparian zones the risks in particularly RR2 and RR3 are increased, which would have a direct negative impact on the refuge role of Ndumo Game Reserve (Figure 10.8 B, D and F). The integrated cumulative risk profiles present a similar trend to those of the individual endpoints. Because of tolerance of amphibians to riparian disturbances the overall improvement of riparian zone (Figure 10.9) is not as pronounced as for some of the other endpoints (i.e. improved by less than a full class). Similarly the deterioration of riparian zone (Figure 10.10) only increased the risk by half a class. The low amplitude a wide base of the distribution is indicative of higher uncertainty in the accuracy of the risk predictions due to riparian zone improvement/reduction.

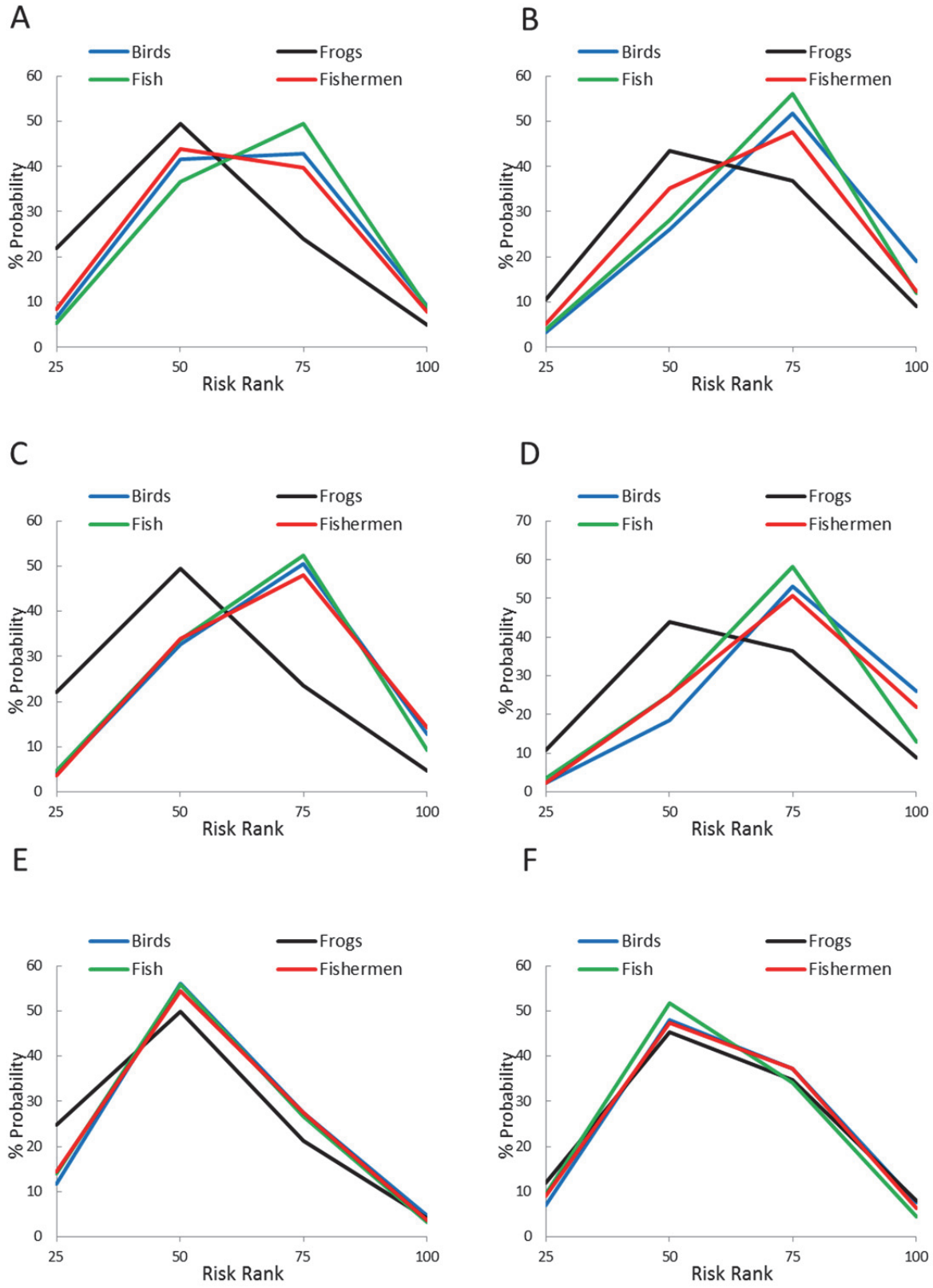


Figure 10.8. Relative risk outcome distributions in the three risk regions following an improvement [Scenario 8: RR1 (A), RR2 (C) and RR3 (E)] and a deterioration [Scenario 9: RR1 (B), RR2 (D) and RR3 (F)] in the riparian zone habitat structure of the Phongolo River and associated pans from the current state scenario.

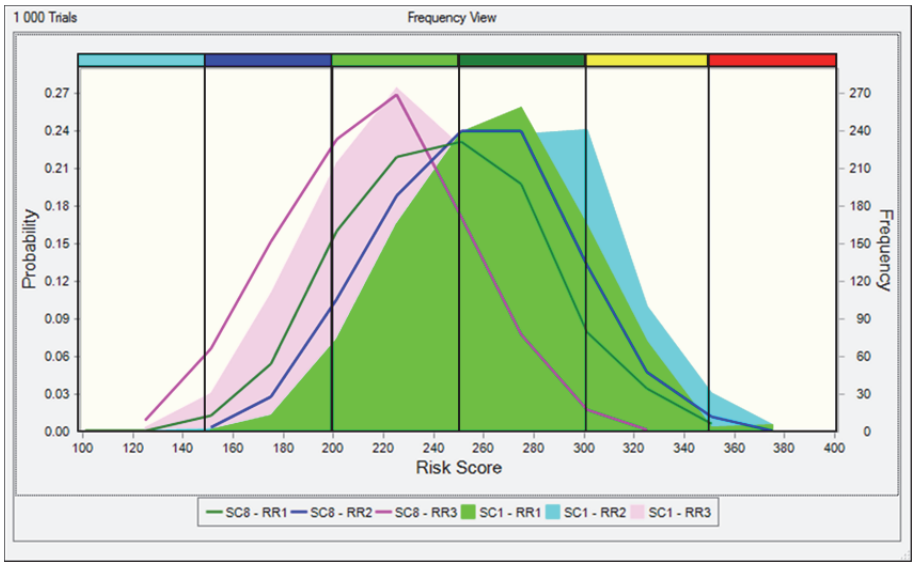


Figure 10.9. Integrated relative risk of all endpoints considered in the study per risk region (RR) for the present state scenario (Scenario 1 – SC1) and allowing the state of the riparian zone to improve (Scenario 8 – SC9).

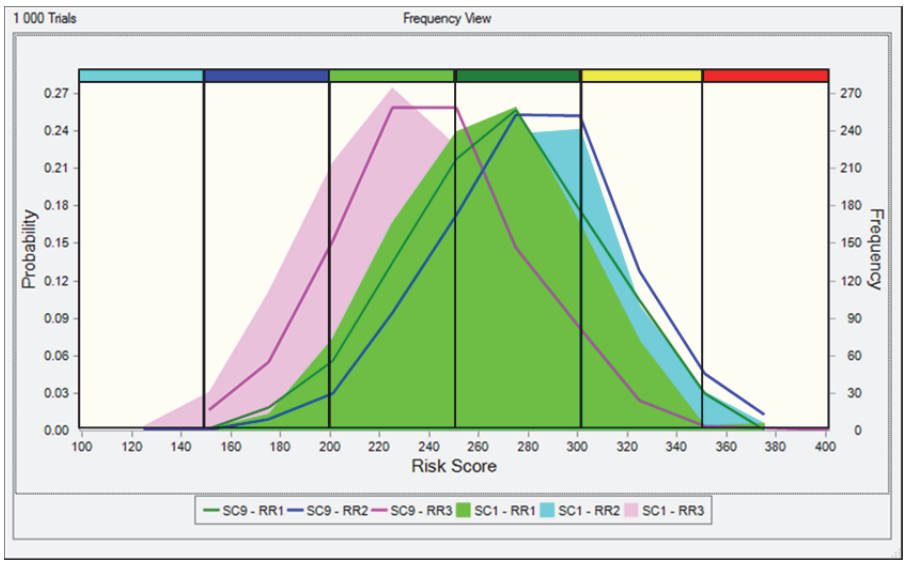


Figure 10.10. Integrated relative risk of all endpoints considered in the study per risk region (RR) for present state scenario (Scenario 1 – SC1) and allowing the state of the riparian zone to deteriorate (Scenario 9 – SC9).

10.4 Comparison of RRM-BN model outputs with EcoStatus output

According to Kleynhans et al. (2005) the EcoStatus can regarded as the totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural floral and faunal biome. The terminology used to describe the different EcoStatus classes is essentially risk-based and therefore allows for comparison

with the integrated BN model based on the common risk categories. For the purposes of this comparison we selected “Maintenance of fish biodiversity” as the endpoint since the confidence in the data was high. The fish model that was applied in the EcoStatus assessment is the Fish Response Assessment Index (FRAI – see Chapter 4 whilst the BN model that was applied was for fish biodiversity (see Figure 9.6). The outputs of the two models are superimposed in Figure 10.11. What is immediately evident is that the BN model provides a graphical representation of the risk distribution between the different categories whereas the FRAI model provides a singular index score within a related risk category. There is a seemingly large discrepancy between the two risk categories for fish biodiversity in RR1, while for both the BN and FRAI models the risk categories for RR 2 and 3 were very similar.

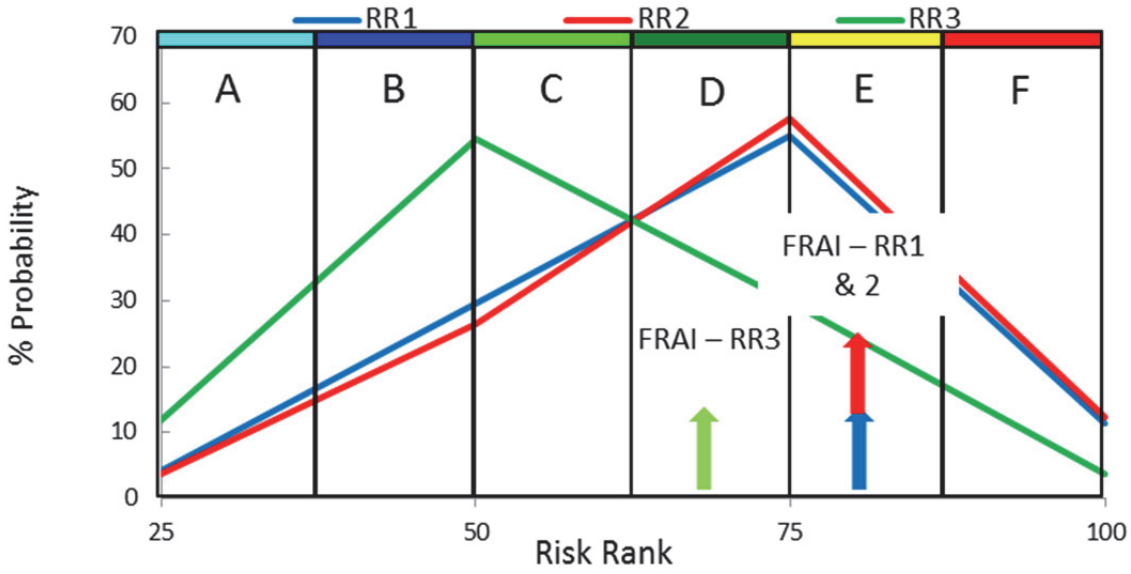


Figure 10.11. The relative risk distribution for the maintenance of fish biodiversity in the three risk regions under current conditions with the FRAI risk categories (arrows) for the same risk regions superimposed.

In RR31 the risk category based on the BN model for maintenance of fish biodiversity was a B/C while the FRAI category was a D. The D category was regarded as an underrepresentation of the fish community in Ndumo Game Reserve and was attributed to the lack of suitable habitat at the site sampled during this study. This uncertainty in the data is reflected in the risk distribution that was calculated for RR3. Even though the category was in a B/C there is a still a high likelihood (40%) that the category could be lower than a C. The sensitivity of both models was demonstrated in that they provided the same results for RR1 and 2. The BN category was slightly higher (D/E) than the FRAI category (E) in these two risk regions. As with the risk distribution for RR3 there was a fair degree of uncertainty since

there also exists an approximately 40% likelihood that the categories could be higher than a D.

10.5 General conclusions

- In this study we demonstrated that the BN approach can effectively be used as a tool for resource and conservation managers.
- We were able to demonstrate that the resource protection afforded to the Ndumo Game Reserve provides a biodiversity refuge in the Phongolo catchment. Through different scenarios, i.e. increased human disturbances in riparian zones as well as increased fisheries, it was demonstrated that the socio-ecological risk distribution in Ndumo Game Reserve would reach similar high risk conditions to those outside of the Reserve.
- Risks posed by changes in both water quantity (in this example a singular parameter change in flood releases) and quality (in this example we used DDT bioaccumulation in aquatic biota) were addressed using the BN model.
- The graphic nature of the interface and outputs coupled to the ability of the BN models to generate and evaluate alternative scenarios makes it a useful tool for resource management.
- The form of the risk distribution curves serves as a sensitivity analysis of the BN model outputs. It therefore provides an indication of where additional information will be required to reduce uncertainty.
- The generation of information to reduce the uncertainty in the risk predictions will in essence drive the structuring of future monitoring programmes, i.e. the monitoring becomes hypothesis driven.
- The new information generated by the monitoring can be used to update the input node descriptions and if necessary the rank scores making the BN model ideal for adaptive management application.
- The application of RRM-BN models can contribute to greater application of adaptive management practices in resource and conservation management in the Phongolo River catchment.
- According to Ayre and Landis (2012) the application value within an adaptive management framework is due to the RRM-BN model communicating uncertainty in a quantifiable manner, the interactions of dispariate ecological values are visually observed through the graphical interface, and once the model has been developed it can easibly be updated and refined by the resource manager, thereby increasing ownership in the adaptive management process.

10.6 Recommendations

- The Relative Risk Methodology that was developed during this project provides an innovative way to contribute to the determination of water resource protection measures and associated objectives as required by the National Water Act (Act 108 of 1998) of South Africa and should be considered by Ezemvelo KZN Wildlife, DEA and DWS as an option. These measures include the Reserve Determination procedures, Water Resource Classification procedures and the Resource Quality Objectives. The outcomes of the risk assessment and the associated evidence (water resource use and protection information, and the proposed and evaluated river quantity, quality, habitat and biota objectives) provide essential information that could be incorporated into the Resource Quality Objectives determination procedures for Water Management Area 6 (including the Phongolo River). Future monitoring can then be incorporated into the RRM model to increase predictive power.
- The model developed in this study should be rolled out to the various stakeholders, including amongst others Ezemvelo KZN Wildlife, DEA and DWS, through workshops focussing on the training of the resource managers in the use and implementation of this model.
- For the purposes of developing the BN-RRM model we only focused on four endpoints covered in this study. In some instances the metrics used to provide causal links between stressors and effects were fairly course, e.g. for the maintenance of fish biodiversity the measure of flooding was only related to habitat availability. Other measures such as role of floods in maintaining ecosystem processes in the floodplain pans will increase the certainty associated with the risk predictions.
- It therefore remains essential that fundamental research be conducted and supported financially in order to provide the necessary data that address these processes.
- One of the outcomes of this project was the first report of the invasive freshwater crayfish, *C. quadricarinatus*, from this region as well as the first report in Africa of its associated parasites. The impacts of this alien and its parasites on indigenous aquatic fauna must be investigated and its current Alien and Invasive Species listing of 1b should be re-assessed.
- High levels of DDT were detected in all the fish species tested and thus pose a potential serious health risk to the local community. The RRM further showed that an increase in current DDT levels will increase human health risks. Based on these finding it is imperative that the continued use of DDT in this area should be re-assessed as well as the current health status of the people of this region should be investigated.

10.7 References

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APPENDIX I: LIST OF MACROINVERTEBRATES COLLECTED IN AQUATIC HABITATS IN THE NDUMO GAME RESERVE (CHAPTER 7)

Family	Genus and species where available
Acarina	
Hydrachnellae	*Hydrachnella*
Annelida	
Oligochaeta	
Coleoptera	
Chrysomelidae	*Donaciasta* sp.
Curculionidae	*Bagous* sp.
Curculionidae	*Neohydromus* sp.
Curculionidae	*Pseudobagous* sp.
Dytiscidae	*Laccophilus*
Dytiscidae	*Copelatus*
Dytiscidae	*Cybister* sp. A
Dytiscidae	*Cybister* sp. B
Dytiscidae	*Rhantaticus/Aethionectes*
Dytiscidae	*Eretes* sp.
Dytiscidae	*Hydrovatus*
Dytiscidae	*Hydrovatus* sp.
Dytiscidae	*Laccobius* sp.
Dytiscidae	*Derovatellus*
Dytiscidae	*Hydroglyphus*
Elmidae	Elmidae larvae
Gyrinidae	*Dineutus* sp.
Haliplidae	*Pelodytes*
Haliplidae	*Haliplus* sp.
Hydraenidae	*Pterosthetops* sp.
Hydrochidae	*Hydrochus* sp.
Hydrophilidae	*Berosus* sp.
Hydrophilidae	*Regimbartia/Allocotocerus*
Hydrophilidae	larva
Hydrophilinae	*Enochrus*
Hydrophilidae	*Regimbartia/Allocotocerus*
Hydrophilidae	*Enochrus*
Noteridae	*Synchortus*
Noteridae	*Neohydrocoptus*
Noteridae	*Canthydrus* sp.
Spercheidae	*Spercheus* sp.
Crustacea	
	Lynceus sp.
Atyidae	*Caridina nilotica*

Appendix I. (continued)

Cladocera	*Simnocephalus exspinosus*
Cladocera	*Ceriodaphnia*
Copepoda	*Macrocyclops*
Cyzicidae	*Cyzicus*
Diaptomidae	*Lovenula*
Diaptomidae	*Metadiaptomus*
Leptestheriidae	*Leptestheria/Leptestheriella*
Limnadiidae	Eulimidae sp.
Limnocytheridae	*Gomphocythere expansa*
Notostraca	*Triops granarius*
Ostracoda	*Podocopida*
Diptera	
	Brachycera sp.
Brachycera	Tabanidae larvae
Stratiomyidae	Stratiomyidae larvae
Ceratopogonidae	*Bezzia* sp.
Chironomidae	Chironomidae – Chironominae
Chironomidae	Orthocladiinae
Culicidae	*Ficalbia* sp.
Culicidae	*Aedes* sp.
Culicidae	*Culex* sp. B
Culicidae	*Anopheles*
Culicidae	*Culex* sp.
Culicidae	*Coquillettidia* larvae (mosquito)
Culicidae	*Anopheles* sp. B
Culicidae	*Culiseta* (mosquito larvae)
Culicidae	*Mansonia* sp.
Dolichopodidae	(pupae)
Muscidae	Ephydrid pupa
Syrphidae	Syrphidae
Tanypodinae	Tanypodinae
Tipulidae	Tipulid pupae
Ephemeroptera	
Baetidae	*Cloeon/Procloeon*
Caenidae	*Caenis* sp.
Hemiptera	
Belostomatidae	*Hydrocyrius*
Belastomatinae	*Limnogeton fieberi*
Belostomatidae	*Appasus*
Corixidae	*Sigara* sp.

Appendix I. (continued)

Corixidae	*Agraptocorixa*
Gerridae	*Naboandelus africanus*
Gerridae	*Tenagogonus* sp.
Gerridae	*Neogerris* sp. *(Neogerris severeni)*
Mesoveliidae	*Mesovelia vittigera*
Naucoridae	*Naucoris* sp.
Naucoridae	*Macrocoris*
Nepidae	*Ranatra*
Nepidae	*Laccotrephes* (water Scorpion)
Nepidae	*Borrelia afzelii* (water scorpion)
Notonectidae	*Anisops* sp. A
Notonectidae	*Nychia limpida*
Notonectidae	*Enithares* sp.*?*
Notonectidae	*Anisops* sp. B
Notonectidae	*Anisops* sp. C
Notonectidae	*Notonecta lactitans*
Pleidae	*Plea*
Hirudinea	
	leech)
Lepidoptera	
	Crambidae larvae
Mollusca	
Ampullariidae	*Lanistes ovum*
Corbiculidae	*Corbicula* sp.
Lymnaeidae	*Lymnaea natalensis*
Lymnaeidae	*Lymnaea truncatula*
Physidae	*Aplexa marmorata*
Physidae	*Physa acuta*
Planorbidae	*Bulinus tropicus*
Planorbidae	*Bulinus natalensis*
Planorbidae	*Bulinus africanus*
Planorbidae	*Bulinus forskalii*
Planorbidae	*Ceratophallus natalensis*
Planorbidae	*Bulinus depressus*
Thiaridae	*Cleopatra sp.*
Thiaridae	*Tarebia granifera*
Viviparidae	*Bellamya capillata*
Odonata	
Aeshnidae	*Anax*

Appendix I. (continued)

Aeshnidae	*Aeshna*
Aeshnidae	*Anaciaeschna*
Coenagrionidae	*Allocnemis leucosticta*
Coenagrionidae	*Enallagma*
Gomphidae	*Lestinogomphus*
Lestidae	*Lestes*
Libellulidae	*Tetrathemis polleni*
Libellulidae	*Trithemis* sp.
Libellulidae	*Orthetrum* sp.
Libellulidae	*Pantala flavescens*
Libellulidae	*Brachythemis lacustris*
Libellulidae	*Parazyxomma flavicans*
Libellulidae	*Diplacodes lefebvrii*
Libellulidae	*Bradinopyga* (*cornuta*)
Protoneuridae	*Ellatoneura glauca*

APPENDIX II: SOCIO-ECOLOGICAL STUDY (CHAPTER 8) QUESTIONNAIRE – PHASE ONE

QUESTIONNAIRE - PHASE ONE

Integrative multidisciplinary Perspectives on Interactions with the Phongolo floodplain

SECTION 1

PREFATORY:

1. Before the questionnaire is submitted to a participant, informed and signed consent is required on the part of the participant.
2. It is hereby affirmed that the information supplied in the questionnaire will be considered private and confidential.

SECTION 2

NAME:

.....

RESIDENTIAL ADDRESS

.....

HOW LONG HAVE YOU RESIDED AT THE ABOVE ADDRESS?

.....

TELEPHONE NUMBER: .....

MALE: .....
FEMALE: .....

AGE: .....

EDUCATIONAL LEVEL: .....

EMPLOYED/ UNEMPLOYED: .....

ETHNIC RELATION: .....

¶

INFORMED CONSENT¶

Interactions with the Phongolo floodplain¶

(related to human well-being and environmental consciousness)¶

¶

I have been informed that the purpose of the research is to explore human awareness, experience and interactions with the Phongolo floodplain and its immediate environment. My participation will involve answering questions related to our community's interactions with the floodplain environment and that the interview will take approximately 15 to 30 minutes. ¶

¶

I understand that there are no foreseeable risks or discomforts if I agree to participate in the study.¶

¶

I understand that the results of the study may be published but that my name or identity will not be revealed. I also understand that the results of the study may be used for secondary studies connected to this project, but that my name or identity will not be revealed. The North-West University will maintain confidentiality of all records and materials.¶

¶

I have been informed that I will not be compensated for my participation. I have been informed that any questions I have concerning this research study or my participation in it before or after my consent, will be answered by the investigators of this study. ¶

¶

I understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefit to myself. In signing this consent form, I am not waiving any legal claims, rights, or remedies.¶

¶

I, the undersigned, _____ (full names), have read and understand the above information and by signing this form indicate that I will participate in the research voluntarily.¶

¶

¶

_____ → → → → _____¶

Participant's signature ···→ → → → Date¶

¶

¶

_____ → → → → _____¶

Investigator's signature ····· → → → Date¶

¶

APPENDIX III: SOCIO-ECOLOGICAL STUDY (CHAPTER 8) QUESTIONNAIRE – PHASE TWO

QUESTIONNAIRE – PHASE TWO

Integrative multidisciplinary perspectives on the psycho-social wellbeing of community and their interactions with the Phongolo floodplain

SECTION 1
PREFATORY:

1. Before the questionnaire is submitted to a participant, informed and signed consent is required on the part of the participant.

2. It is hereby affirmed that the information supplied in the questionnaire will be considered private and confidential.

SECTION 2
NAME

.....

RESIDENTIAL ADDRESS

.....

HOW LONG HAVE YOU RESIDED AT THE ABOVE ADDRESS?

……

TELEPHONE NUMBER: .....

MALE: ……..
FEMALE:……

AGE:……..

EDUCATIONAL LEVEL:……..

EMPLOYED/ UNEMPLOYED:……

ETHNIC RELATION: ……..

INFORMED CONSENT

Psycho-socio wellbeing of communities residing in the Ndumo area in the lower Phongolo floodplain

I have been informed that the purpose of the research is to broadly explore the psycho-socio wellbeing of humans, awareness and experience in general as well as fish interactions with the Phongolo floodplain. My participation will involve answering questions related to our community's interactions with the floodplain environment and that the interview will take approximately 15 to 30 minutes.

I understand that there are no foreseeable risks or discomforts if I agree to participate in the study.

I understand that the results of the study may be published but that my name or identity will not be revealed. I also understand that the results of the study may be used for secondary studies connected to this project, but that my name or identity will not be revealed. The North-West University will maintain confidentiality of all records and materials.

I have been informed that I will not be compensated for my participation. I have been informed that any questions I have concerning this research study or my participation in it before or after my consent, will be answered by the investigators of this study.

I understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefit to myself. In signing this consent form, I am not waiving any legal claims, rights, or remedies.

I, the undersigned, _____ (full names), have read and understand the above information and by signing this form indicate that I will participate in the research voluntarily.

_____ _____

Participant's signature Date

_____ _____

Investigator's signature Date

Qualitative follow-up study, PHASE TWO:

Determining the psycho-social wellbeing of communities residing in the Ndumo area close to the Lower Phongolo floodplain

Research questions guiding data gathering:

- What are the sources of psycho-social wellbeing in these communities?
- What types of psycho-social resources exist in these communities?
- What are the biggest psycho-social challenges faced by people in these communities?
- What role does religion and spirituality play in the well-being of the community?
- Why are so many people (81.8%) single in this community?

Possible questions to guide structured interviews:

- What are the things (in this community) that make you happy / satisfied? What else? (Probe for specifics).
- What are the things (in this community) that make you unhappy / dissatisfied? What else? (Probe for specifics).
- What are the biggest challenges people living in this community face? (Probe for specifics)
- What are the most important things that make you / people in this community strong / able to cope with these challenges? (Probe for specifics).
- Is religion important to you? If so, please explain in what ways it is important to you? How specifically does it help you? / Is religion important in this community? Why? (Probe for specifics).
- It seems to us as if many people in these communities are not married. Do you agree with this? If so, why do you think this is? (Probe for specifics).

APPENDIX IV: SOCIO-ECOLOGICAL STUDY (CHAPTER 8) QUESTIONNAIRE – PHASE THREE

PHONGOLA QUESTIONNAIRE – PHASE THREE

Integrative multidisciplinary perspectives on wellbeing and interactions with the Phongolo floodplain

SECTION 1
PREFATORY:

1. Before the questionnaire is submitted to a participant, informed and signed consent is required on the part of the participant.

2. It is hereby affirmed that the information supplied in the questionnaire will be considered private and confidential.

SECTION 2
NAME

.....

RESIDENTIAL ADDRESS

.....

HOW LONG HAVE YOU RESIDED AT THE ABOVE ADDRESS?

……

TELEPHONE NUMBER: .....

MALE: ……..
FEMALE:……

AGE:……..

EDUCATIONAL LEVEL:……..

EMPLOYED/ UNEMPLOYED:……

ETHNIC RELATION: ……..

INFORMED CONSENT

Interactions with the Phongolo River and floodplain

I have been informed that the purpose of the research is to understand my interactions with the local fishing industry. My participation will involve answering questions related to the catching, selling or consumption of local fish species and that the interview will take approximately 15 to 30 minutes.

I understand that there are no foreseeable risks or discomforts if I agree to participate in the study.

I understand that the results of the study may be published, but that my name or identity will not be revealed. I also understand that the results of the study may be used for secondary studies connected to this project, but that my name or identity will not be revealed. The North-West University will maintain confidentiality of all records and materials.

I have been informed that I will not be compensated for my participation. I have been informed that any questions I have concerning this research study or my participation in it before or after my consent, will be answered by the investigators of this study (prof Elize S van Eeden [016 910 3469]; Dr. Hendri Coetzee [018-299 4348]; Dr Werner Nell and Dr Engela P de Crom).

I understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefit to myself. In signing this consent form, I am not waiving any legal claims, rights, or remedies.

I, the undersigned, _____ (full names), have read and understand the above information and by signing this form indicate that I will participate in the research voluntarily.

Participant's signature: _____ Date: _____

Investigator's signature: _____ Date: _____

QUESTIONNAIRE FOR FISH CONSUMERS (END USERS), SUPPLIERS (LOCAL FISHERMEN) AND TRADERS

Section A: Questions to be completed by ALL respondents

1. Age: _____

2. Gender:

1 Male	2 Female

3. Where do you live? _____

4. For how many years have you been living in this area? _____ years

5. Satisfaction with life	Strongly disagree	Disagree	Slightly disagree	Neither agree nor disagree	Slightly agree	Agree	Strongly agree
a. In most ways my life is close to my ideal.	1	2	3	4	5	6	7
b. The conditions of my life are excellent.	1	2	3	4	5	6	7
c. I am satisfied with my life.	1	2	3	4	5	6	7
d. So far I have gotten the important things I want in my life.	1	2	3	4	5	6	7
e. If I could live my life over, I would change almost nothing.	1	2	3	4	5	6	7

6. During the past month, how often did you feel	Never	Once or twice	About once a week	About 2 or 3 times a week	Almost every day	Every day
a. happy	1	2	3	4	5	6
b. interested in life	1	2	3	4	5	6
c. satisfied	1	2	3	4	5	6
d. that you had something important to contribute to society	1	2	3	4	5	6
e. that you belonged to a community (like a social group, or your neighbourhood)	1	2	3	4	5	6
f. that our society is becoming a better place for people like you	1	2	3	4	5	6
g. that people are basically good	1	2	3	4	5	6
h. that the way our society works makes sense to you	1	2	3	4	5	6
i. that you liked most parts of your personality	1	2	3	4	5	6
j. good at managing the responsibilities of your daily life	1	2	3	4	5	6
k. that you had warm and trusting relationships with others	1	2	3	4	5	6
l. that you had experiences that challenged you to grow and become a better person	1	2	3	4	5	6
m. confident to think or express your own ideas and opinions	1	2	3	4	5	6
n. that your life has a sense of direction or meaning to it	1	2	3	4	5	6

7. How religious / spiritual do you consider yourself to be?

0 – not at all	1 – slightly	2 – moderately	3 – very	4 – extremely

8. What is your marital status?

1 – Married	2 – Single (never married)	3 – Divorced	4 – Widowed

9. Who do you live with? (Tick all that apply)

I live alone	Spouse	Boy/girlfriend	Child/ren	Grandparent/s	Friend/s	Other relative/s

Section B: Questions for consumers of fish

10. How much do you weigh?

1 Below 50 kg	2 51-60 kg	3 61-70 kg	4 71-80 kg	5 81-90 kg	6 91-100 kg	7 Above 100 kg

11. How would you rate your own health?

1 Poor	2 Below average	3 Average	4 Above average	5 Good

If you indicated that your health is below average or poor, please indicate the health concerns you experience:

_____

_____

_____

12. How often do you eat each of the following?

	Never or almost never	1-3 times per month	About once a week	Several times a week	Almost every day
Fish	1	2	3	4	5
Sheep	1	2	3	4	5
Goat	1	2	3	4	5
Beef	1	2	3	4	5
Chicken	1	2	3	4	5
Game/bush meat	1	2	3	4	5
Other (specify) _____	1	2	3	4	5

13. How many times **per week** do you usually eat fish?

1 x per week	2 x per week	3 x per week	4 x per week	5 x per week	6 x per week	7 x per week

14. How many times **per day** do you eat fish on days when you do eat fish?

1 x per day	2 x per day	3 x per day

15. Why do you eat fish (tick all that apply)?

1 I can catch it for free	2 It is cheap / affordable	3 I like the way it tastes	4 It is easily available	5 It is healthy	6 Can easily/quickly prepare a dish with fish

16. Does your diet remain more or less the same over the course of each year, or does it change?

Same	Changes

If your diet changes at different times of the year, please explain **when** and **how** it changes:

_____

_____

17. How do you get the fish?

1 I catch it myself	2 I get/buy it from family/friends	3 I get/buy it from an unrelated person

18. If you buy fish, where do you buy the fish?

1 Vendor in nearby town	2 Vendor in my own village	3 Vendor next to the road (not in town or village)	4 Other source: _____

19. Are you aware of any social and/or cultural activities or rituals where fish or fishing play an important role?

1 Yes	2 No

If so, please tell us more about it:

_____

_____

20. Which of the following species do you eat?

Species	**Yes**	**No**	**Nr per week**
Red-breasted Tilapia (*Isibungwana/Isikhwambi*)	1	2	
Brown squeaker (*Inkonkonko*)	1	2	
Silver catfish (*Umwensa*)	1	2	
Mozambique tilapia (Isikhwambi)	1	2	
Tiger fish (*Uklangwe*)	1	2	
Sharp tooth catfish (*Ubhabhule*)	1	2	
Red claw crayfish	1	2	
Other:_____	1	2	

21. Have you experienced any changes in the price of fish sold over the last 10 years?

1 Prices decreased a lot	2 Prices decreased slightly	3 Prices remained the same	4 Prices increased slightly	5 Prices increased a lot

Section C: Questions for local fishermen

22. For how many years have you been fishing in this area? _____years

23. Where do you catch most of your fish (tick all that apply)?

1	2	3
River	Pan Place name:_____	Other places (if so, indicate_____)

24. At how many locations do you fish most of the time?_____

25. Do you catch more fish at some times of the year than others?

1	2	3	4
No, it's the same all year round	Yes, I catch more fish in summer	Yes, I catch more fish in winter	Yes, I do, but it is not related to the seasons

26. How do you select the specific location where you fish (tick all relevant options)?

1	2	3
Accessible (close)	Because there are lots of fish	It is safe there
4 It is easy to fish there (not many rocks, plants and other obstacles)	5 Other reason: _____	

27. Is the fish you catch for (tick all that apply):

1	2	3
Personal consumption?	Selling?	Other uses? (if so, indicate_____)

28. What methods do you use to catch the fish (tick all that apply)?

1	2	3	4	5	6
Hand line	Fishing rod	Gill net	Drag net	Traditional method (e.g. baskets)	Other method: _____

29. Have you experienced any changes in the number of fish in the local rivers and pans over the last 10 years?

1	2	3	4	5
Big decrease	Small decrease	No change	Small increase	Big increase

30. In your opinion, in the last few years, have the average **sizes** of the fish:

1	2	3	4	5
Decreased a lot	Decreased a little	Stayed the same	Increased a little	Increased a lot

31. Have you noticed a change in the type of species that you catch within the past couple of years? If so, when did this change start?

1	2	3
Yes	No	When:_____

Please explain what changes you noted (if any):

_____

_____

32. What type (species) of fish do you catch, and how many of each type do you typically catch per week?

Species	Yes	No	Nr per week
Red-breasted Tilapia (*Isibungwana/Isikhwambi*)	1	2	
Brown squeaker (*Inkonkonko*)	1	2	
Silver catfish (*Umwensa*)	1	2	
Mozambique tilapia (Isikhwambi)	1	2	
Tiger fish (*Uklangwe*)	1	2	
Sharp tooth catfish (*Ubhabhule*)	1	2	
Red claw crayfish	1	2	
Other: _____	1	2	

33. Have you ever noticed large-scale deaths in your local fish population?

1	2	3
Yes, often	Yes, but not often	No

If so, where and when did you see this?

_____

_____

34. Does fishing play a significant role in your culture or local traditions?

1	2
Yes	No

If so, please tell us how:

_____

_____

35. To what extent do the following things make it more difficult to catch fish?

	It has no effect	It has a small effect	It has a big effect
There are less fish in the rivers and pans these days	1	2	3
The pans and rivers sometimes get dry	1	2	3
The release of water from the dam interferes with fishing	1	2	3
There are too many other fishermen	1	2	3
When it rains a lot fishing becomes difficult	1	2	3
Other:_____			

Section D: Questions for traders (those who sell fish but who are NOT fishermen)

36. For how many years have you been selling fish in this area? _____years

37. Are there more fish available at some times of the year than others?

1	2	3	4
No, it's the same all year round	Yes, there are more fish in summer	Yes, there are more fish in winter	Yes, there are, but it is not related to the seasons

38. How do you sell the fish?

1	2	3	4
Fresh fish (whole)	Dried fish	Deep-fried	Other format (specify):_____

39. Where do you get/buy the fish from?

1	2
Local fishermen	Other suppliers: Please specify_____

40. Where do you mostly sell your fish?

1	2	3	4	
In your own village	In another village	In a nearby town	Next to the road	Other:_____

41. (a) How many fish do you typically sell per week; and (b) what is your average price of the following species per average sized fish?

Species	(a) Nr. sold per week	(b) Average price
Red-breasted Tilapia (*Isibungwana/Isikhwambi*)		R
Brown squeaker (*Inkonkonko*)		R
Silver catfish (*Umwensa*)		R
Mozambique tilapia (Isikhwambi)		R
Tiger fish (*Uklangwe*)		R
Sharp tooth catfish (*Ubhabhule*)		R
Red claw crayfish		R

42. Have you experienced any changes in the availability of fish over the last 10 years?

1	2	3	4	5
Big decrease	Small decrease	No change	Small increase	Big increase

43. What species of fish do your customers prefer most, and why?

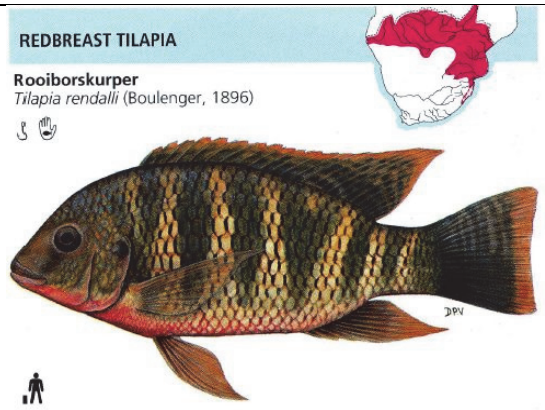
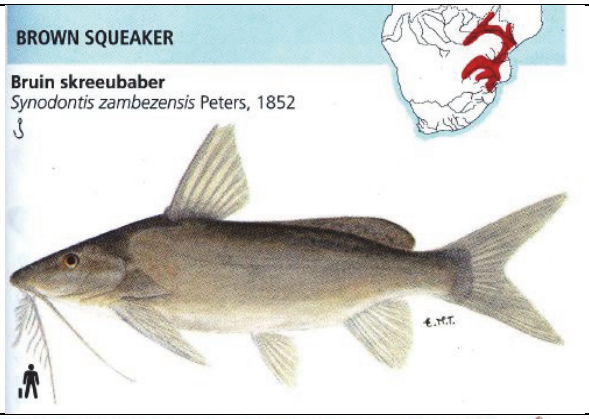
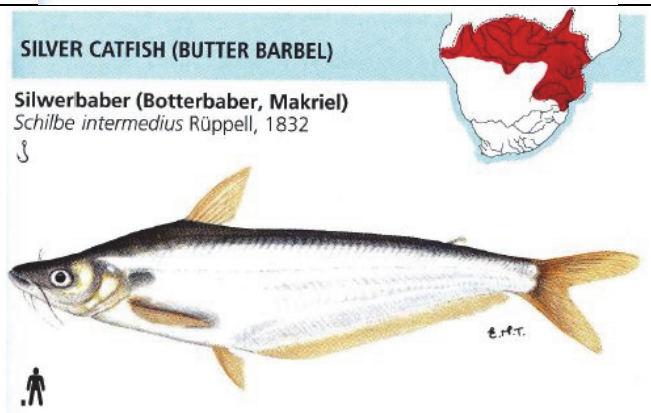
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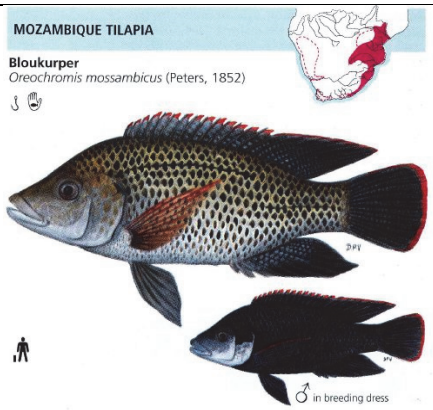
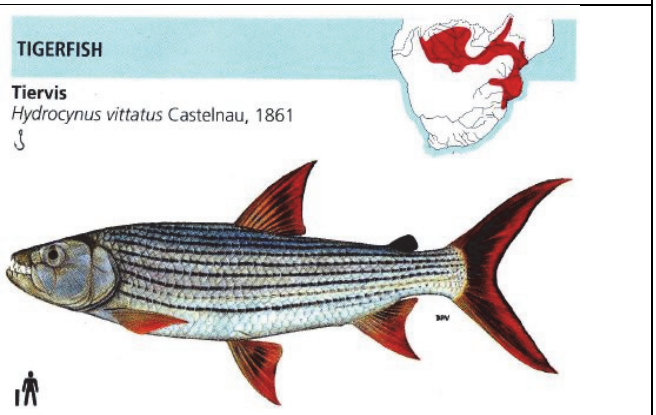
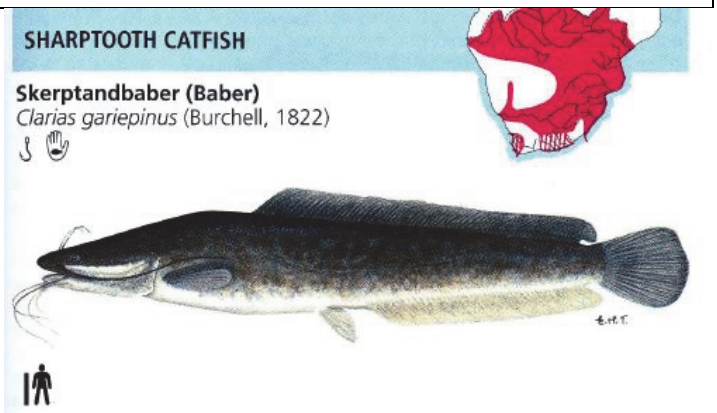
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THANK YOU VERY MUCH FOR YOUR TIME!

APPENDIX IV (CONTINUED): FISH SPECIES UTILIZED BY PARTICIPANTS

Fish Identification Kit (Pongola River and floodplain project)

Species names	
Red-breasted Tilapia (*Isibungwana/Isikhwambi*) 	
Brown squeaker (*Inkonkonko*) 	
Silver catfish (*Umwensa*) 	

Mozambique tilapia (Isikhwambi) 	
Tiger fish (*Uklangwe*) 	
Sharp tooth catfish (*Ubhabhule*) 	
Red claw crayfish 	