Amphibian diversity and Community-Based Ecotourism in Ndumo Game Reserve, South Africa

FM Phaka

orcid.org/0000-0003-1833-3156

Previous qualification (not compulsory)

Dissertation submitted in fulfilment of the requirements for the *Masters* degree in *Environmental Science* at the North-West University

Supervisor: Prof LH du Preez
Co-supervisor: Dr DJD Kruger
Assistant Supervisor: Mr EC Netherlands

Graduation May 2018
25985469

NORTH-WEST UNIVERSITY
NOORDWES-UNIVERSITEIT
UNIBESITI YA BOKONE-BOPHIRIMA

Declaration

I, Fortunate Mafeta Phaka, declare that this work is my own, that all sources used or quoted have been indicated and acknowledged by means of complete references, and that this thesis was not previously submitted by me or any other person for degree purposes at this or any other university.

Signature .... Date 18/11/2017 ....

Acknowledgements

A great debt of gratitude is owed to my study supervisor L.H. Du Preez, co-supervisor D.J.D. Kruger, and assistant supervisor E.N. Netherlands for guidance and encouragement to focus on my strengths. To my mentors, D. Kotze and L. De Jager, and the Phaka clan, your faith in me has kept me going through all these years. Thank you to African Amphibian Conservation Research Group and Youth 4 African Wildlife for accepting me as part of your family. Members of the Zululand community are thanked for their enthusiasm and assistance towards this study.

Fieldwork and running expenses for this research were funded by the South African National Biodiversity Institute's (SANBI) Foundational Biodiversity Information Programme (Grant UID 98144). Financial assistance for studying towards this degree was provided by SANBI's Foundational Biodiversity Information Programme (National Research Foundation Grant-Holder Linked Bursary for Grant UID 98144), and the North-West University (NWU Masters Progress Bursary, and NWU Masters Bursary).

Ezemvelo KZN Wildlife is thanked for research permit OP 4092/2016 (see Appendix A). Furthermore, Ndumo Game Reserve and Tembe Elephant Park are thanked for allowing me to conduct fieldwork on their property.

Ethics approval for this study was obtained from the North-West University Institutional Research Ethics Regulatory Committee's (NWU-IRERC) AnimCare Animal Research Ethics Committee (AREC-130913-015) and issued with ethics number NWU-00348-16-A5 (see Appendix B).

Abstract

Amphibian diversity is declining at an alarming rate globally. Monitoring of amphibian communities is lax, yet vital to their conservation and understanding of their decline. Conservation areas often harbour rich biodiversity along with high anuran species richness. High human population density generally correlates positively with this high biodiversity, and consequently, high human population numbers are associated with an increased threat to biodiversity. This trend is evident at Ndumo Game Reserve (NGR), which falls within the internationally recognised Maputaland-Pondoland-Albany Biodiversity Hotspot. The reserve is surrounded by rapidly growing, primarily rural settlements. The pressure on biodiversity grows as the human population increases. There is also risk to human wellbeing since a threat to biodiversity translates into a threat to the integrity of ecosystems on which people and wildlife depend.

The conflict between conservation and development hampers attempts at effectively curbing the ongoing loss of biodiversity. Community-based conservation initiatives including Community-Based Ecotourism (CBE) present a means of satisfying both development and conservation objectives. This study contributes to amphibian conservation through the surveying and monitoring of amphibians and investigates various aspects of amphibian diversity at NGR. Results obtained from this study are applied to a community-based conservation initiative for NGR. Additionally, this study provides a supplementary benefit by promoting information and communications technology (ICT) use in an area of low development. Furthermore, the gap between people and biodiversity has been lessened through development of an English-isiZulu handbook on the frogs of Zululand. The book represents the first indigenous language guide to frogs in South Africa. This initiative serves as a pilot for introducing CBE based on amphibian diversity. It also is aimed at broadening understanding of amphibians across South Africa.

Keywords; Anura, Citizen Science, Conservation, Frogging Eco-tours, KwaZulu-Natal, Information and Communications Technology, Maputaland-Pondoland-Albany, Monitoring.

Isifushaniso Samaphuzu

Ukutholakala kwezimfibiya (amphibians) ngezinhlobo ezehlukahlukene kuncipha ngesivinini esethusayo. Akugqizwa qakala ukubekwa iso kwezimfibiya ezisekhona [emhlabeni], nokho kubaluleke kakhulu ekulondolozweni kwazo nasekuqondweni kokuncipha kwazo. Izindawo zokulondoloza ziqukethe eziningi izinhlobo (species) zamasele namaxoxo kanye namanye ama-*taxon* (amaqoqo ezinto eziphilayo anokuhlobana) ahlukahlukene. Ngokujwayelekile, ubukhona bezinhlobo ezihlukahlukene zezinto eziphilayo kuheha abantu abazohlala ndawonye endaweni; okwenza ukuthi ubuningi obukhulu babantu buhlotshaniswe nokukhula kokusongelwa kobukhona bezinhlobo ezihlukahlukene zezinto eziphilayo. Lesi simo sisobala eSiqiwini Sezinyamazane SaseNdumo (Ndumo Game Reserve), esiwela ngaphakathi kweSigodi Esivelele Sezinto Eziphilayo Ezehlukahlukane esiqashelwa ezingeni lamazwe omhlaba i-Maputaland-Pondoland-Albany futhi esizungezwe yizindawo ezihlala abantu ikakhulu zasemaphandleni ezikhula ngokushesha. Ngokwanda kwesibalo sabantu iyakhula ingcindezi phezu kwezinto eziphilayo ezihlukahlukene, kanjalo kwande nengcuphe empilweni enhle yabantu. Ukuphazamiseka kwezinto eziphilayo ezihlukahlukene kusho ukuphazamiseka kozinzo ohlelweni lokusebenzisana kwezinto zemvelo ezakhelene okuyinto abantu nezilwane zasendle abancike kuyo.

Ukungqubuzana okuphakathi kokulondolozwa [kwemvelo] nokuthuthukiswa [kwezindawo zabantu] kuyayithiya imizamo yokunqandwa okushaya emhloleni kokushabalala okuqhubekayo kwezinto eziphilayo ezihlukahlukene. Imizamo yokulondoloza ezinze emphakathini, ehlanganisa i-*Ecotourism* Ezinze Emphakathini iveza indlela yokwenelisa kokubili imigomo yokuthuthukisa neyokulondoloza. Lolu cwaningo (study) luyitshe esivivaneni sokulondolozwa kwezimfibiya okwenziwa ngokuthungatha izimfibiya nokuzibeka iso futhi luphenya izici ezihlukahlukene zezinhlobo zezimfibiya eSiqiwini Sezinyamazane SaseNdumo. Imiphumela etholakale kulolu cwaningo iyahunyushwa ngezinjongo zomzamo wokulondoloza ozinze emphakathini ngokuqondene neSiqiwu Sezinyamazane SaseNdumo. Ngaphezu kwaloko, lolu cwaningo lugqugquzela ukwaziswa (information) nobuchwepheshe bokuxhumana ngokusebenzisa i-aplikesheni yocingo oluphathwayo njengosizo lokuwethula ezithebeni lowo mzamo. Ukwenezela lapho, igebe phakathi kwabantu nezinto eziphilayo ezihlukahlukene lincishiswa ngokufaka isandla ekuthuthukisweni kolimi lomdabu, okwenziwa

ngesokuqala eNingizimu Afrika isiqondiso sasefilidini sezilimi ezimbili isiNgisi nesiZulu, ngamaxoxo akwelaKwaZulu. Lo mzamo usebenza njengohlelo oluyisibonelo lokwethula i-Ecotourism Ezinze Emphakathini ngokwehlukahluka kwezimfibiya nokusabalalalisa kakhudlwana ukuqondwa kwezimfibiya kulo lonke elaseNingizimu Afrika.

Amazwi ayinhloko; Amaxoxo Namasele (Anura), Isayensi Yezakhamuzi, Ukulondoloza, Ukuthungatha Amaxoxo, KwaZulu-Natali, Ubuchwepheshe Bokwaziswa Nokuxhumana, i-Maputaland-Pondoland-Albany, Ukubeka Iso, I-Ecotourism (Ukuvakashela Izindawo Ezisebenza Ngokwemvelo).

Table of Contents

List of Acronyms

AACRG	African Amphibian Conservation Research Group
AREC	AnimCare Animal Research Ethics Committee
CBD	Convention on Biological Diversity
CBE	Community-Based Ecotourism
DCA	detrended correspondence analysis
DEA	Department of Environmental Affairs
GIS	Geographic Information System
GPS	Global Positioning System
ICT	information and communications technology
IUCN	International Union for Conservation of Nature
KZN	Kwazulu-Natal
MCS	manual call surveys
NBSAP	National Biodiversity Strategy and Action Plan
NGR	Ndumo Game Reserve
NWU	North-West University
NWU-IRERC	North-West University Institutional Research Ethics Regulatory Committee
PAM	passive acoustic monitoring
RDA	redundancy analysis
SANBI	South African National Biodiversity Institute
Stats SA	Statistics South Africa
UN	United Nations
UN DESA	United Nations Department of Economic and Social Affairs

List of Figures

List of Tables

Chapter 1: General Introduction

1.1 Introduction

Amphibians (Class Amphibia) can be considered pioneers of vertebrate terrestrial life. Their emergence is estimated to have occurred as early as 323.3 million years ago (Pyron 2011). Since then, amphibians have diversified into one of the most successful and specious vertebrate groups (Roelants et al 2007). These common ancestors of all terrestrial vertebrates have survived three of the five mass extinction events in earth's history. The latest and most renowned of these occurrences was in the Cretaceous and is estimated to have resulted in the extinction of almost 76% of all species on earth (Alvarez et al, 1980; Prauss 2009; Archibald et al 2010). While all dinosaurs (Class Reptilia) went extinct, amphibians experienced very little family level extinction at that time (Macleod et al 1997) and continued to colonise hospitable habitats.

Despite surviving unfavourable conditions in the past, amphibians are exhibiting less resilience to conditions in the current era. Amphibian diversity is under threat as the class is considered the most threatened among vertebrate taxa today (Wake 1991; Stuart et al 2004; Bishop et al 2012). Out of the 7 727 amphibian species known at the drafting of this thesis (Frost 2017), around 42% are to some extent threatened with extinction (IUCN 2017a). Recent amphibian extinctions have been too frequent to be considered 'background extinction' (Roelants et al 2007). A myriad of factors, including accelerated climate change, diseases, habitat loss, and overexploitation are cited as contributors to this decline (Kiesecker et al 2001; Stuart et al 2004; Weldon et al 2004; IUCN 2017a). Although different in their effects, many of the factors contributing to global amphibian declines have human influence as a common denominator (Collins and Storfer 2003). Various authors have indicated that amphibians are vital to ecosystem health (Minter et al 2004; Du Preez and Carruthers, 2009; Bishop et al 2012); their decline may even threaten the survival of human populations as ecosystems are increasingly hampered in their ability to support life.

The rapid increase of human population around the globe translates into increased threat for amphibian diversity and ultimately a risk to ecosystem health and in turn to human survival. This interplay between amphibian declines and human population growth presents a conflict between conservation and development which needs to be resolved. Conservation areas are at the coalface of this problem as they are generally characterised by high biodiversity and there is usually a positive correlation between high biodiversity and dense human population along with its associated pressure on biodiversity (Balmford et al 2001).

The above trend is apparent in Ndumo Game Reserve (NGR), the area forming the focus of this study. This reserve is situated in Kwazulu-Natal (KZN) which is the province with the highest amphibian diversity in South Africa (see Lambiris 1988; Minter et al 2004; Measey 2011). The country as a whole has 128 amphibian species (Frost 2017) and at least 73 of these (including subspecies) are found in KZN (Du Preez and Carruthers 2017). The study area (NGR), falls within the Zululand region of KZN, which boasts 54 amphibian species (see Minter et al 2004, Du Preez and Carruthers 2017; Minter et al 2017). A conservation area or nature reserve as defined by South African legislation refers to an area with significant biodiversity, of scientific or cultural interest, or in need of long-term protection to maintain its biodiversity in order to provide a sustainable flow of natural products and services to fulfil various socio-economic needs and wants (Protected Areas Act 57 of 2003).

Zululand forms part of the Maputaland-Pondoland–Albany Biodiversity Hotspot (Mittermeier et al 2011). Ndumo Game Reserve is itself a biodiversity hotspot in Zululand (see Pringle and Kyle 2002; Haddad 2003; Haddad et al 2006) and one of the few conservation areas in this biodiversity rich region. The last comprehensive amphibian survey for this region was conducted by Lambiris (1988) almost 30 years ago. Such large-scale amphibian surveys are necessary for detailed studies of amphibian populations and help inform conservation planning (Measey et al 2011b). There is a need to replicate the work conducted by Lambiris (1988) on a regular basis given its importance to amphibian conservation planning. South Africa's 2017 Biodiversity Management Plan for Pickergill's Reed Frog (*Hyperolius pickergilli*) provides an example of how regular monitoring of amphibian populations can inform conservation planning (DEA 2017).

One of KZN's major biodiversity threats is habitat loss (Measey 2011). An estimated 1.2% of natural habitat in the province has been transformed per annum between 1994 and 2011 to fulfil various human needs and wants (Jewitt et al 2015). In 2005 an estimated 43% of KZN had been transformed (Jewitt et al 2015), compared to a 15.7% transformed national land area (Schoeman et al 2013). The province of KZN also has high human population numbers. It is one of the country's smallest provinces accounting for only 7.7% of total land area, yet it is the second most populous with an estimated 19.6% of South Africa's total population living in KZN (see Stats SA 2012; Stats SA 2017). The rapid increase of South Africa's human population is well documented with an estimated overall growth rate increase from approximately 1,17% between 2002 and 2003 to 1,61% for the period 2016 to 2017. (Stats SA 2017; UN DESA 2017). The country's environmental issues are also well documented, with some of the drivers of biodiversity loss including accelerated climate change, alien invasive species, habitat loss, and overexploitation of natural resources (Fuggle and Rabie 2009).

Habitat loss is presented as the greatest threat to South Africa's amphibians (Stuart et al 2004). Fuggle and Rabie (2009) highlight the ongoing struggle between human population needs and biodiversity when they mention that the ultimate causes of this biodiversity loss are socio-economic in nature. Historically, there was not enough evidence to prove whether these biodiversity loss drivers are causing decline of amphibians in South Africa (Channing and Van Dijk 1995). Declines of amphibian species recorded in Southern Africa are limited to the local population level and mostly recorded at areas directly affected by drivers of biodiversity loss (Minter et al 2004). Failure to regularly analyse population trends could result in long-term amphibian declines going unnoticed during monitoring (Measey et al 2011a).

The regularity of amphibian population trend analysis has increased with recent studies. In 2004, 17% of South African amphibians were assessed to be threatened while in 2010 the proportion of threatened amphibians was 14.3% (Angulo et al 2011). The latest IUCN (2017b) assessment data available during drafting of this thesis shows that at least 12.5% of the country's amphibians are threatened. At least 68 species are estimated to have experienced a decrease in distribution range since 1996 (Botts et al 2012). This suggests that at least 53% of South Africa's amphibians are experiencing decline. Botts et al (2013) recorded range contractions for endemic species and also concluded that species with narrow habitat and climate niches are more likely to experience more severe range contractions as a result of increased human impact on the environment. Frog species found in the Bushveld and Winter

Rainfall regions are exhibiting a north-westerly range shift in response to accelerated climate change, while Bushveld species are additionally moving upslope (Botts et al 2015).

The dilemma in South Africa, as with the rest of the world, is that development degrades the environment but it is necessary to cater for people's socio-economic needs. Conservation is also vital to people's survival but it is often perceived to hamper development. This conflict between conservation and development objectives has played out at NGR for many years and at times even turned violent (Meer and Schnurr 2013). The area around NGR is predominantly rural and subsistence agriculture is still practiced. No utilisation of amphibians in the communities surrounding NGR was recorded in this study. Popular perceptions towards frogs are mostly negative in these communities. For example, toads are thought to be the cause of lightning strikes. Such negative perceptions create problems for conservation initiatives in the area as local understanding of and relatability to biodiversity is required for these initiatives to have a better chance of succeeding.

Community-based conservation initiatives, including Community-Based Ecotourism (CBE), are seen as a way of minimising this conflict between conservation and development objectives by working towards achieving both simultaneously (Meer and Schnurr 2013). Ndumo Game Reserve includes community-based conservation principles in its management approach as a way to benefit both people and wildlife (Meer and Schnurr 2013). There is, however, a gap in efforts directed at conserving amphibian diversity in a way that will also benefit people living around the reserve. This study explores various aspects of amphibian diversity at NGR and how local communities could benefit from this diversity while simultaneously protecting it.

Getting local people interested in conservation is a challenge conservation areas face and well-designed efforts to bridge this gap can lead to increased understanding of environmental matters and engagement in conservation initiatives (Brewer 2002). This in turn increases chances of success for conservation initiatives. Local education levels are also an important determinant for the success of conservation initiatives. Higher education generally corresponds with stronger conservation perspectives (Stem et al 2003b).

1.2 Study Aims and Objectives

The aims of this study are as follows:

Aim 1. Document amphibian species diversity within Ndumo Game Reserve:

Objective A. Understand NGR's amphibian diversity by undertaking a comprehensive survey using both active and passive techniques.

Aim 2. Compare historic species records with current data for the same area:

Objective A. Gather historical data about all the frog species previously detected in the study area by various researchers (Wager 1965; Lambiris 1988, Minter et al. 2004; Ezemvelo KZN Wildlife) and compare it with data from current study.

Aim 3. Relate species occurrence to sampling covariates:

Objective A. Record various sampling covariates along with all survey data in order to understand amphibian habitat utilisation at NGR;

Objective B. Document the surveyed microhabitats and categorise them according to appropriate systems (endorheic, lacustrine, palustrine, riverine, or terrestrial).

Aim 4. Pilot means to effectively make biodiversity data relatable to non-scientists.

Objective A. Understand the Zululand community's perceptions relating to frogs through consultations;

Objective B. Train Ezemvelo KZN Wildlife staff and members of communities around NGR to identify frogs and sensitize them to amphibian extinction risk;

Objective C. Incorporate frogs into the list of tourist attractions at NGR;

Objective D. Combine historical and recent data on Zululand frog species with lessons learned about the community's perception of frogs to aid in compiling a guide for frogs of the Zululand region.

1.3 Alignment with National and International Strategies

Aichi Biodiversity Targets (CBD 2011) recognise the disconnect of people from biodiversity as a contributor to biodiversity loss. Mainstreaming biodiversity issues across the Zululand community would contribute to lessening this disconnect, thus lessening the rate of biodiversity loss while simultaneously working towards Aichi Biodiversity Target's Strategic Goal A. This strategic goal requires the underlying causes of biodiversity loss to be addressed by mainstreaming biodiversity across society (CBD 2011). Additionally, the research's popular outputs, which include South Africa's first frog hand book to be written in an indigenous language, hold educational value for the Zululand community and worth for NGR's tourism. Such outputs are in line with Aichi Biodiversity Target's Strategic Goal D, which calls for an enhancement of biodiversity and ecosystem services (CBD 2011).

By seeking to lessen such disconnect and improve biodiversity protection through increasing understanding of biodiversity issues the project aims to contribute to achieving Millennium Development Goal 15. This development goal is geared towards sustainable development of natural resources and curbing biodiversity loss (UN 2000). South Africa's 2015 National Biodiversity Strategy and Action Plan (NBSAP) speaks of biodiversity that provides South Africans with a rich heritage of nature-based cultural traditions and further reiterates the significance of wildlife to the country's cultures (DEA 2015). The research outcomes intended for the non-scientist are a response to NBSAP's acknowledgement that biodiversity is not as broadly understood as it should be. This current study also contributes to improving public knowledge of an endangered frog as provided for by the Biodiversity Management Plan for *Hyperolius pickergilli* (DEA 2017).

1.4 Outline of Thesis

This thesis consists of five chapters, including this short introductory chapter (**Chapter 1).** The subsequent chapters cover three main themes. **Chapter 2** focuses on amphibian diversity and various aspects thereof while **Chapter 3** focuses on aspects of habitat utilisation by amphibian diversity. The third theme, presented in **Chapter 4**, explores how social and conservation benefits can be derived from biodiversity studies. The thesis concludes with **Chapter 5** as a summative discussion, followed by a list of references, and appendices.

1.4.1 Summary of chapters

Chapter 2 reports on amphibian diversity at NGR as documented in this current study and compares it to historical records. It additionally investigates whether the rapidly increasing human activity outside NGR's borders has affected amphibian diversity inside the reserve over time. In **Chapter 3** habitat utilisation by amphibians within NGR is investigated from various contexts. In **Chapter 4** different ways of making scientific research, specifically biodiversity research, relatable to non-scientists are explored and the possibility of using community-based conservation initiatives as a means of fulfilling both amphibian conservation and human population objectives is investigated. The entire study is then summed up and recommendations for future studies made in **Chapter 5**, which is followed by a list of references (using the *African Zoology* journal format) and appendices.

Chapter 2: Amphibian Diversity at Ndumo Game Reserve

2.1 Introduction

2.1.1 General introduction to amphibian diversity

The diversity and composition of Amphibia has changed drastically since emergence of the class. Most of the 7 727 extant amphibian species (Frost 2017) appeared relatively late on the amphibian evolutionary timeline (Roelants et al 2007). Hotspots of this current amphibian diversity include South America, Africa, and the south-eastern part of North America (IUCN 2016). From a climatic perspective, these hotspots are mostly associated with tropical and sub-tropical areas. The current amphibian taxonomic rank is divided into three orders, namely the Anura, Caudata, and Gymnophiona. Anura is the most diverse of the three orders with 6 806 species, followed by Caudata with 714 species, while Gymnophiona comprises only 207 species (Frost 2017). This diversity contributes immensely to global vertebrate fauna diversity (Frost et al 2006).

2.1.2 Southern Africa's amphibian diversity

Southern Africa has high biodiversity, and of the three amphibian orders only Anura occurs in the region (Measey 2011). Anuran diversity in this region comprises 170 described species grouped into 13 families and 34 genera (Du Preez and Carruthers 2017). Southern Africa's high diversity of fauna and flora is linked to the region's varied climate and landscapes. The landscape ranges from deserts to forests and from mountains to low-lying coastal areas. Climatic conditions range from arid conditions in the west to humid conditions in the east, and rainfall increases from west to east. The climate also becomes more tropical towards the north-eastern part of the region (Allan et al 1997).

Amphibian diversity exhibits a correlation to the region's rainfall; the arid western part is characterised by low amphibian diversity while the more humid east to north-eastern part has a high diversity of amphibians (see Minter et al 2004; Measey 2011; Du Preez and Carruthers 2017). Poynton's (1964) evolutionary perspective on Southern African amphibian diversity provides that historical global warming and cooling resulted in the high diversity found in the north-eastern part of Southern Africa. Due to past warming, northern African tropical species moved towards Southern Africa, and southern frog species moved north-east.

Global cooling then resulted in the independent evolution of species due to isolation while the northern African tropical species most likely established themselves in the more suitable north-eastern part of Southern Africa (Poynton 1964).

2.1.3 KwaZulu-Natal's amphibian diversity

South Africa's KZN province falls within the subtropical north-eastern part of the country and has a vast variety of habitats that are suitable for frogs (see Alexander et al 2004; Measey 2011). This province is part of one of the few globally recognised biodiversity hotspots, the Maputaland-Pondoland-Albany Biodiversity Hotspot (Mittermeier et al 2011). KwaZulu-Natal has the highest amphibian diversity of any South African province (Lambiris 1988; Angulo et al 2011; Measey 2011). The province is an important area for amphibian endemism (Alexander et al 2004). Four Endangered and three Near Threatened amphibian species are found in KZN (IUCN 2017b). It is also an important hotspot for other taxonomic groups besides amphibians (see Haddad et al 2006; Tolley et al 2008). The impact of human population on this biodiversity has increased over the years (Driver et al 2005). This threatens the province's amphibian diversity and makes conservation areas all the more valuable in the preservation of this diversity.

2.1.4 Ndumo Game Reserve: KwaZulu-Natal's biodiversity hotspot

In the northern part of KZN lies a conservation area, Ndumo Game Reserve (NGR), which is renowned as a biodiversity hotspot for various taxa, including amphibians, within the province. Northern KZN is part of Zululand, an area where the African Amphibian Conservation Research Group (AACRG) conducted a comprehensive amphibian biodiversity survey, of which this study is a component. Zululand, as defined in this study, covers an area that stretches east from the Lebombo mountains along the South Africa/Mozambique border to the coast, then along the coast towards the longitude line nearest Richards Bay, and from there north along that longitude line towards the Lebombo mountains (Figure 2.1).

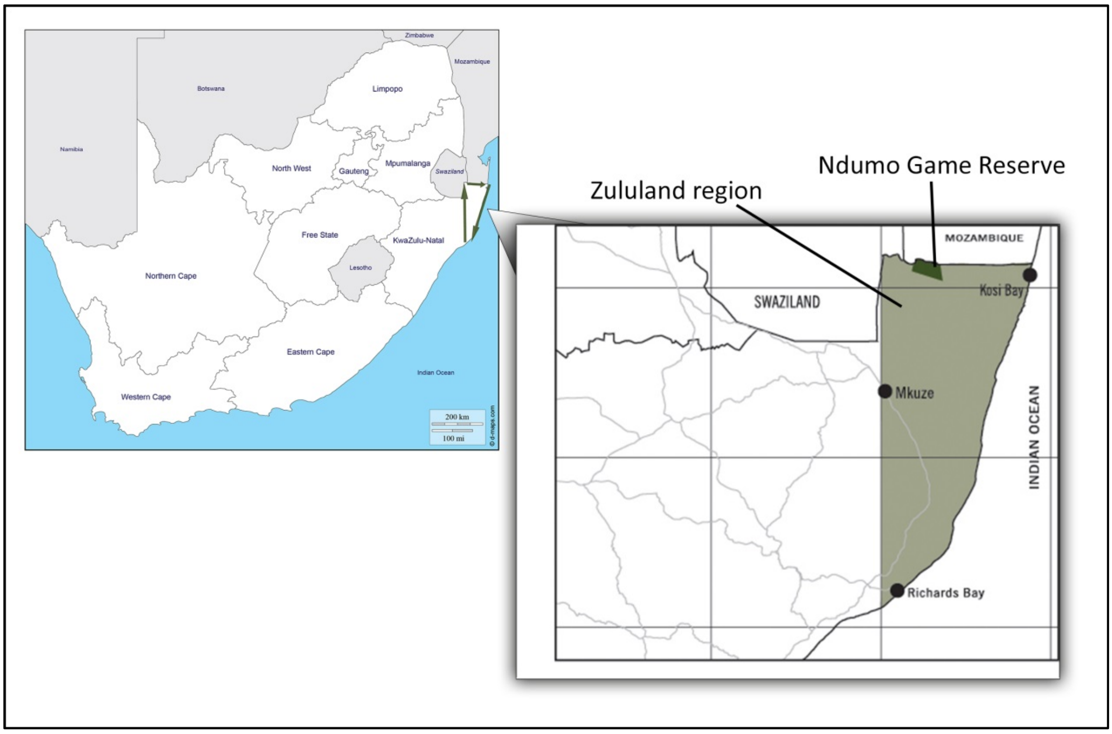


Figure 2.1: Ndumo Game Reserve as a study site in relation to the larger study area of Zululand.

The diversity of various taxa within NGR has been surveyed by several studies in the past. Some of the diversity reported to occur inside this nature reserve includes; 25 species of fruit-chafers (Haddad 2003), 116 butterfly species (Pringle and Kyle 2002), 457 species of non-acarine arachnids (Haddad et al 2006), and over 400 different bird species (K.L. Tinley and W.T. van Riet, unpubl. data 1981). At the time of the study by Haddad et al (2006), their survey recorded the highest number of spider species within a single South African reserve. A study by Netherlands (2014) is one of the few recent surveys of amphibians within NGR. Current estimates of amphibian diversity at NGR, and Zululand in general, are mainly based on historical data obtained from Wager (1965), Lambiris (1988), Minter et al (2004) and Ezemvelo KZN Wildlife's (Ezemvelo) species accounts records.

2.1.5 Amphibian diversity survey

General amphibian surveys start with a habitat survey and are undertaken for a broad range of objectives in addition to providing a snapshot of species' presence, absence, abundance, or spatial distribution (Hill et al 2005). Anurans are frequently heard and not seen.

Vocalisations are an important part of anuran communication. Thus, the detection of species-specific calls is often used as the primary method of investigation and is also a relatively efficient mechanism for studying and evaluating their populations (Dorcas et al 2009). Anurans have a vast array of acoustic properties (Duellman and Trueb 1986). These properties influence detection probability when using manual call surveys (MCS) (Dorcas et al 2009). Temporal variation in frog calling activity may result in failure to detect some species (Bridges and Dorcas 2000). Some calls may carry for long distances while others can only be heard at a 100 m or less from the calling site (Dorcas et al 2009).

In species-rich communities, species that call at lower frequencies may be overshadowed by species which call at higher-pitched frequencies (Droege and Eagle 2005). Manual call surveys work best for communities where all species vocalise during a relatively predictable breeding season. This sampling technique should not be used as the exclusive survey method for species that breed in response to heavy localised rain, have relatively low frequency calls, call infrequently or have relatively short breeding seasons (Dorcas et al 2009). Abiotic factors have an effect on frog calling behaviour (Blair 1961) and thus are likely to influence detection using MCS. Anthropogenic noise can also affect detection as frogs react to the presence of observers, thus it is advisable to wait a few minutes after arriving at a site before commencing with MCS (Dorcas et al 2009).

Imperfect detection is an inherent problem in most wildlife monitoring programs as sampling areas may be too large to survey completely and few animals are so conspicuous that all individuals can be detected in a single study (MacKenzie et al 2002). Combinations of multiple methods in a single survey can complement each other and lessen the degree of imperfect detections. Netting and funnel traps for aquatic environments, and visual encounter surveys for both aquatic and terrestrial environments are relatively efficient methods for determining the presence of anurans (Hill et al 2005). Supplementing these with other sampling techniques would further increase the efficiency of your survey.

2.1.6 Importance of surveys and long-term monitoring of amphibian communities

Amphibians are ecological indicators that give signals about the overall health of ecosystems (Morell 1999; Wake and Vredenburg 2008). They are an important link in the food chain since they serve as both prey and predator species (Hirai and Matsui 1999; Du Preez and Carruthers 2009). Frogs provide larger predators with a food source, and both their adult and larval forms control insect populations by preying on them. They are essential to science as they help researchers better understand terrestrial vertebrate evolution.

In comparison with other vertebrates, amphibians are at the forefront of the current extinction event (Kiesecker et al 2001; Mendelson et al 2006; Wake and Vredenburg 2008). The rapid decline of amphibian communities translates to a reduction in their contribution to science and ecosystem integrity. This decline could possibly threaten ecosystem health and have knock-on effects for species which prey on frogs and species preyed on by frogs. Surveys and long-term monitoring of amphibian communities contributes to understanding their declines. Owing to their importance to ecosystems, Minter et al (2004) contends that plans to protect amphibian diversity should form an integral part of conservation planning.

2.2 Materials and Methods

2.2.1 Site selection

The chosen study site, NGR, falls on the South African side of the border with Mozambique (Figure 2.1). Ndumo Game Reserve covers an area of 10 117 ha (Grant and Thomas 1998) and is characterised by a rich variety of macrohabitats including Subtropical Vegetation and Sand Forest (De Moor et al 1977). This reserve which is under the management authority of Ezemvelo, has a variety of microhabitats which are suitable for frogs and also contribute to its high species diversity. These microhabitats were used as this study's sampling sites. The sampling sites were divided into five different microhabitat types (Table. 2.1) as defined by Du Preez and Carruthers (2009).

Table 2.1: Microhabitat definitions according to Du Preez and Carruthers (2009).
Endorheic microhabitats: Temporary, rain-filled depressions depleted by absorption and evaporation. Such habitats are neither fed nor drained by a watercourse.
- Pan: A waterbody that varies in size from hectares to a few square meters. It may hold water for prolonged periods but rarely ever on a permanent basis. Hydrophytes are usually present in the water and the banks may either be muddy, or inundated with grass, reed beds, and overhanging trees. **- Pool:** Small depressions that fill up with water after rain, without retention of the water for prolonged periods. Plants growing here are usually not specialised.
Lacustrine microhabitats: A body of water greater than 8 ha, situated in topographic depressions and dammed river channels. Over 70% of the surface is without emergent vegetation.
- Lake: large, naturally occurring body of freshwater. **- Dam:** catchment of water using a human-made or topographic impediment against the flow of a watercourse.

Table 2.1 continued

Palustrine microhabitats: Shallow marshland that is less than two meters in depth, with a surface of more than 30% covered by emergent hydrophytes.
- Vlei: Part of a watercourse which spreads out over a flat valley forming a marshy wetland with inundated grass and specialised water-based vegetation.
Riverine microhabitats: Watercourses that are contained within a channel except in times of flooding.
- Temporary stream: A seasonal flow of water in a natural channel. **- Floodplain:** A flat or depressed area on a watercourse's banks that is periodically inundated and may retain floodwater once the watercourse recedes.
Terrestrial microhabitats: Ecological systems without any conspicuous waterbody.
- Forest floor: The ground below the woodland canopy, generally humid, with a top layer of leaf litter.

In total, 25 sites were sampled. These were sites deemed suitable for amphibians and safe and accessible for sampling. Figure 2.2 shows the location of these sampling sites. Names and site descriptions are provided in Table 2.2 while Figure 2.3 contains a reference photograph of each of the sites. Sampling sites were assigned names according to those officially in use at NGR and sites without official names were allocated new names.

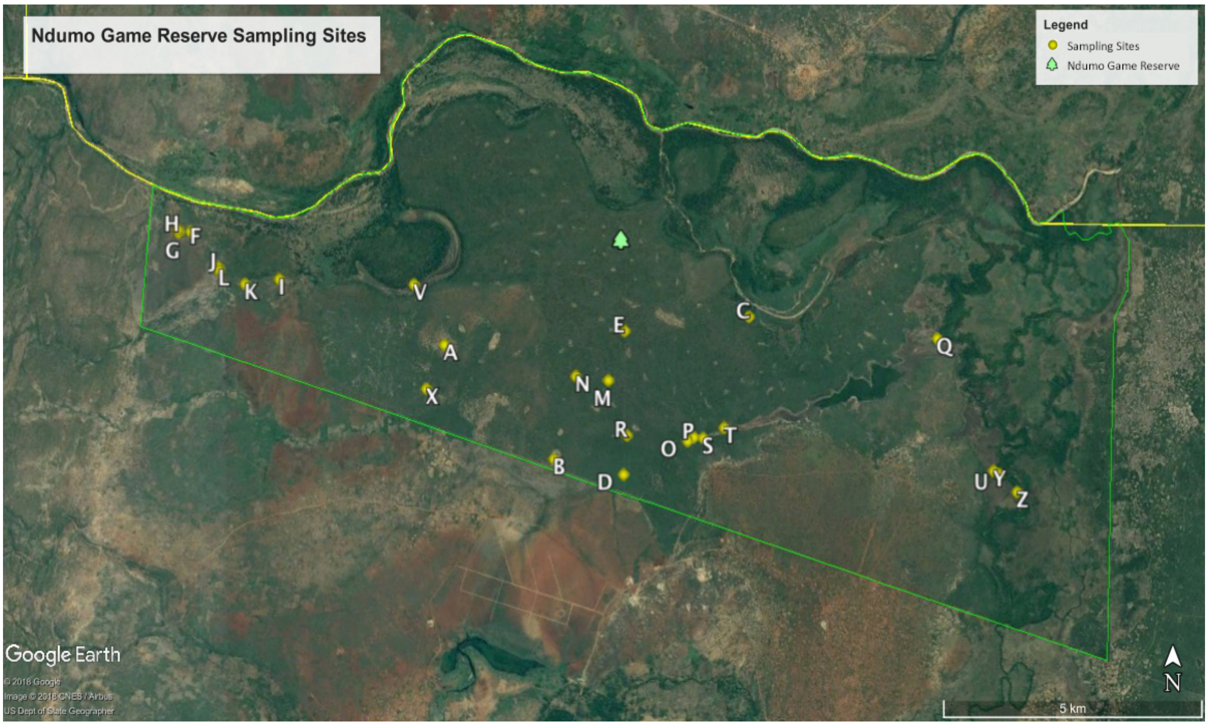


Figure 2.2. Location of Ndumo Game Reserve sampling sites.

A – Balemhlanga floodplain. **B** – Balemhlanga wetland. **C** – Banzi. **D** – Mahemane dam. **E** – Mahemane pan. **F** – Matendeni pan 1. **G** – Matendeni dam. **H** – Matendeni pan 2. **I** – Matendeni stream 1. **J** – Matendeni pan 3. **K** – Matendeni stream 2. **L** – Matendeni pan 4. **M** – Mgagabuleni pan 1. **N** – Mgagabuleni pan 2. **O** – Mjanshi red dam. **P** – Mjanshi stream. **Q** – Nyamithi broken bridge. **R** – Nyamithi stream 1. **S** – Nyamithi stream 2. **T** – Nyamithi stream 3. **U** – Pumphouse dam. **V** – Shokwe. **X** – Ziphosheni pan. **Y** – Terrestrial site 1. **Z** – Terrestrial site 2.

Table 2.2: Name, location, and description of Ndumo Game Reserve sampling sites.

	Site Name	Coordinates	Description
1.	Balemhlanga floodplain (Figure 2.3: A)	S 26.89754° E 32.21578°	Riverine and Lacustrine microhabitat. A Floodplain that gets inundated by an existing watercourse during flooding, holding its water for most of the year due to periodically being fed by light rains that do not result in flooding.
2.	Balemhlanga wetland (Figure 2.3: B)	S 26.90278° E 32.23705°	Palustrine microhabitat. A vlei area with a lot of emergent vegetation and mostly surrounded by Acacia trees.
3.	Banzi (Figure 2.3: C)	S 26.87936° E 32.27495°	Lacustrine microhabitat. One of NGR's naturally occurring lakes.
4.	Mahemane dam (Figure 2.3: D)	S 26.90533° E 32.25062°	Lacustrine microhabitat. A natural watercourse partly dammed by Mahemane road and a depression.
5.	Mahemane pan (Figure 2.3: E)	S 26.88170° E 32.25082°	Endorheic microhabitat. A temporary pan that appears along Mahemane road after rain.
6.	Matendeni pan 1 (Figure 2.3: F)	S 26.86542° E 32.16650°	Endorheic microhabitat. A temporary pan that appears along Matendeni road after rain. One of the several pans that occur along this path after sufficient rain.

Table 2.2 continued

7.	Matendeni dam (Figure 2.3: G)	S 26.86554° E 32.16415°	Lacustrine microhabitat. A watercourse flowing along Matendeni road, dammed by a topographic depression.
8.	Matendeni pan 2 (Figure 2.3: H)	S 26.86511° E 32.16400°	Endorheic microhabitat. A temporary pan that appears along Matendeni road after rain.
9	Matendeni stream 1 (Figure 2.3: I)	S 26.87322° E 32.18371°	Riverine microhabitat. A part of a watercourse flowing along Matendeni road and feeding a dam formed by a topographic depression.
10.	Matendeni pan 3 (Figure 2.3: J)	S 26.87125° E 32.17188°	Endorheic microhabitat. A temporary pan that appears along Matendeni road after rain.
11.	Matendeni stream 2 (Figure 2.3: K)	S 26.87401° E 32.17707°	Riverine microhabitat. A temporary stream that flows across Matendeni road after significant amounts of rain.
12.	Matendeni pan 4 (Figure 2.3: L)	S 26.87173° E 32.17200°	Endorheic microhabitat. A temporary pan that appears along Matendeni road after rain.
13.	Mgagabuleni pan 1 (Figure 2.3: M)	S 26.88984° E 32.24765°	Endorheic microhabitat. A temporary pan that appears after heavy rain.

Table 2.2 continued

14.	Mgagabuleni pan 2 (Figure 2.3: N)	S 26.88917° E 32.24134°	Endorheic microhabitat. A temporary pan that appears after heavy rain.
15.	Mjanshi red dam (Figure 2.3: O)	S 26.89983° E 32.26305°	Lacustrine microhabitat. A natural watercourse partly dammed by Mjanshi road and a topographic depression.
16.	Mjanshi stream (Figure 2.3: P)	S 26.89919° E 32.26426°	Riverine microhabitat. A stream forming part of the channel that feeds Nyamithi lake.
17.	Nyamithi broken bridge (Figure 2.3: Q)	S 26.88289° E 32.31153°	Lacustrine microhabitat. A natural watercourse partly dammed by a topographical depression and a disused bridge as it flows into Lake Nyamithi lake.
18.	Nyamithi stream 1 (Figure 2.3: R)	S 26.89891° E. 32.26819°	Riverine microhabitat. A stream forming part of the channel that feeds Nyamithi lake.
19.	Nyamithi stream 2 (Figure 2.3: S)	S 26.89933° E 32.26607°	Riverine microhabitat. A stream forming part of the channel that feeds Nyamithi lake.
20.	Nyamithi stream 3 (Figure 2.3: T)	S 26.89762° E 32.27015°	Riverine microhabitat. A stream forming part of the channel that feeds Nyamithi lake.
21.	Pump House dam (Figure 2.3: U)	S 26.90521° E 32.32361°	Riverine microhabitat. A depression in the stream forming part of the channel that feeds Nyamithi lake.

Table 2.2 continued

22.	Shokwe (Figure 2.3: V)	S 26.87409° E 32.20987°	Lacustrine microhabitat. One of NGR's naturally occurring lakes.
23.	Ziphosheni pan (Figure 2.3: X)	S 26.89124° E 32.21229°	Endorheic microhabitat. A temporary pan that holds its water for a while after rain.
24.	Terrestrial site 1 (Figure 2.3: Y)	S 26.90468° E 32.32251°	Terrestrial microhabitat. The surface substrate that forms part of NGR forest dominated by *Acacia* trees.
25.	Terrestrial site 2 (Figure 2.3: Z)	S 26.90814° E 32.32707°	Terrestrial microhabitat. The ground surface of part of NGR forest without *Acacia* trees, canopy dominated by a variety of species.

The data for this study was obtained from historical species accounts, long-term monitoring using a Song Meters (Song Meter^{TM} model SM2 and SM3; Wildlife Acoustics Inc., Concord, Massachusetts), as well as a field survey of NGR. The long-term monitoring data was obtained from Mantendeni pan 1 (Figure 2.3: F) and Mahemane pan (Figure 2.3: E). The field survey was conducted from 22 November 2016 to 14 December 2016, using a mixture of both passive and active sampling methods.

Figure 2.3. Ndumo Game Reserve sampling sites.

A – Balemhlanga floodplain. **B** – Balemhlanga wetland. **C** – Banzi. **D** – Mahemane dam. **E** – Mahemane pan. **F** – Matendeni pan 1. **G** – Matendeni dam. **H** – Matendeni pan 2. **I** – Matendeni stream 1. **J** – Matendeni pan 3. **K** – Matendeni stream 2. **L** – Matendeni pan 4. **M** – Mgagabuleni pan 1. **N** – Mgagabuleni pan 2. **O** – Mjanshi red dam. **P** – Mjanshi stream. **Q** – Nyamithi broken bridge. **R** – Nyamithi stream 1. **S** – Nyamithi stream 2. **T** – Nyamithi stream 3. **U** – Pumphouse dam. **V** – Shokwe. **X** – Ziphosheni pan. **Y** – Terrestrial site 1. **Z** – Terrestrial site 2.

2.2.2 Historical data

Historical data from different sources was consulted to establish a baseline of amphibian diversity in Zululand. These historical species records range from 1929 to 2003 and were obtained from Wager (1965), Lambiris (1988), Minter et al (2004) and Ezemvelo database of all frog species encountered in northern KZN. Amphibian diversity data for NGR was then extrapolated from the abovementioned sources.

2.2.3 Passive sampling

Three different passive sampling methods were used for both diurnal and nocturnal sampling. Passive acoustic monitoring (PAM) was carried out using a Song Meter (i.e. programmable acoustic recording device) permanently stationed at two NGR sampling sites for long-term monitoring and recording of calling and breeding activity by AACRG. The Song Meters which are reliable long-term biodiversity monitoring tools, also recorded ambient temperature data to go with the call data of multiple frog species.

The two Song Meters (Figure 2.4: A) used in long-term monitoring were programmed to record for 10 minutes every hour between 18h00 and 05h00 on a daily basis. One Song Meter was placed at Matendeni pan 1 (Figure 2.3: F) to record advertisement call data from April 2013 to April 2014, and another was set at Mahemane pan (Figure 2.3: E) to record from November 2015 to December 2016. A rechargeable battery connected to a solar panel powered these recording devices to ensure they had sufficient power. A third Song Meter was mobile and it was used to sample sites after they had been actively sampled. The latter meter was left to record for 10 minutes every hour for 24 hours at all sampling sites except terrestrial sites.

Xenopus traps (Figure 2.4: B) were baited with chicken liver placed in gauze bags, to collect aquatic frog species. The traps were set in shallow waters of different sites and anchored by a rope tied to vegetation. Precautions were taken to prevent submersion of the entire trap to ensure trapped specimens could surface for oxygen. The third passive sampling method used was drift fence pitfall traps (pitfall traps). These were arranged in a cross shape at two forest microhabitats to detect presence of forest-floor dwelling species (Figure 2.4: C). Three more pitfall traps were installed in a longitudinal fashion at Balemhlanga wetland and Ziphosheni pan to detect movement in response to absence/presence of water in addition to ascertaining presence of frog species (Figure 2.4: D). Two-meter-long and 30cm-high drift fences were set up in a longitudinal manner near known frog microhabitats. Each end of the fencing had two 5L buckets buried in the ground on both sides as pitfalls. Metal rods were used to secure the fencing and parts of it buried in the ground to avoid frogs passing underneath, but rather channelling them to the pitfalls. For the cross-shaped pitfall trap (Figure 2.4: C), the two drift fences crossed each other in the middle at a 90° angle. Each of the four points of this cross had a 5L bucket as a pitfall for frogs being channelled by the drift fence.

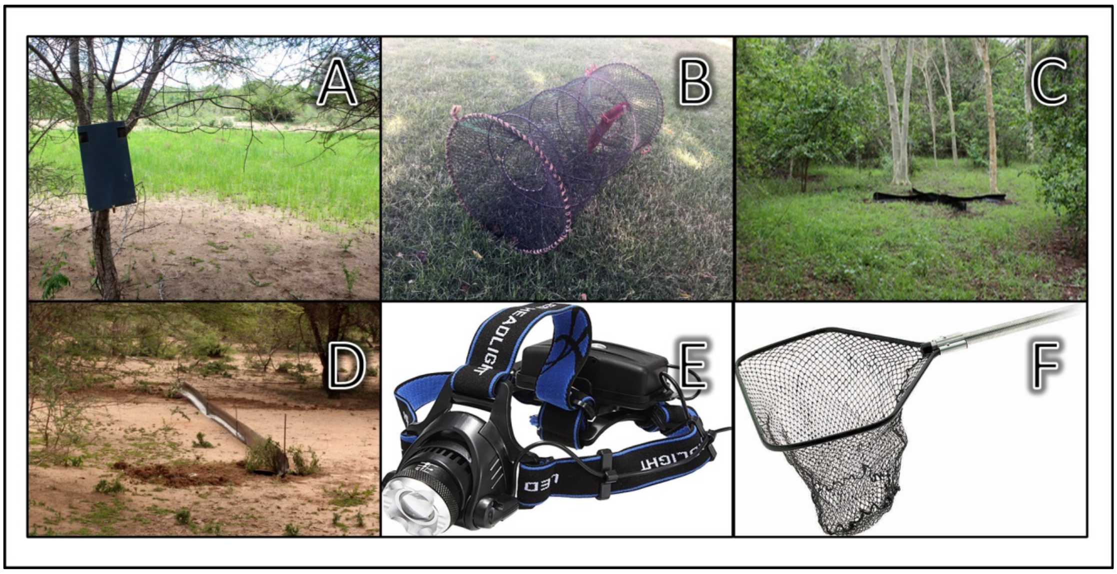


Figure 2.4: Active and passive sampling equipment.

A – Song Meter in a protective case placed at a sampling site. **B** – *Xenopus* trap. **C** – cross-shaped drift fence pitfall trap, **D** – Longitudinal pitfall trap. **E** – High luminance headlamp. **F** – Dip net.

2.2.4 Active sampling

Active sampling involved four different sampling techniques. Terrestrial searches, MCS and visual encounter surveys were used for sampling at night. During the day MCS, terrestrial searches and dip netting were employed. Manual call surveys involved listening to the advertisement calls of different male frogs and recording all species detected at a site. To minimise misidentification from advertisement calls a frog identification mobile phone application was used for confirmation. The audio playback function of the "Complete Guide to the Frogs of Southern Africa" mobile software application (Frog App) was used to listen to frog advertisement calls and thus confirm species identity (Du Preez and Carruthers 2015). The MCS were carried out five minutes after arrival at a sampling site and were also employed while using other active sampling methods.

Terrestrial searches involve scouring each site and recording all species encountered per site. Visual encounter surveys require walking along the banks of a water body at night with a high luminance headlamp (Figure 2.4: E) and recording species seen at parts of the water body that could not be accessed while doing terrestrial searches. Visual encounter surveys help detect individuals that were not calling and could not be detected through MCS. Dip netting involves intensive sweeping of water bodies at different breeding sites for one minute using a dip net (Figure 2.4: F). The netted tadpoles are then identified to ascertain the presence of particular species, especially species that may have moved away from a site after breeding.

2.2.5 Handling specimens

All specimens were collected by hand (Ezemvelo Permit OP 4092/2016). Specimens that required additional inspection of morphological features for identification purposes were transferred to plastic containers with damp vegetation while being identified. After identification each frog was released at the original site of collection. The Frog App (Du Preez and Carruthers 2015) and a field guide written by Du Preez and Carruthers (2009) were used as aids for identification of specimens to species level.

Tadpoles sampled via dip netting were identified using a dissection microscope to magnify their small features. These tadpoles were anaesthetised with Tricaine methanesulfonate (MS-222) mixed with water before looking at their distinguishing traits through a dissection microscope. Following identification, they were transferred to clean water for recovery then returned to their original site of capture.

2.2.6 The effect of increasing human population pressure on amphibian diversity

It has been previously mentioned that a rapidly growing human population places pressure on biodiversity (see Balmford et al 2001; Ceballos and Ehrlich 2002; Crist et al 2017). To ascertain whether the increase in human population outside NGR was affecting the reserve's amphibian diversity, the study investigated associations between human population growth trends, proportion of natural habitat in KZN and amphibian diversity inside the reserve. By studying the correlation between the three variables mentioned above an inference on the effect of increasing human population on NGR amphibian diversity could be made. Calculating the correlation coefficient of these variables allowed further inferences to be made about the effects of human population and habitat loss on NGR amphibian diversity. Plotting the three variables allowed for visualisation of their relationship and prediction of future trends.

2.3 Results: Amphibian Diversity at Ndumo Game Reserve

2.3.1 Historical versus current frog diversity at Ndumo Game Reserve

Historical records (from 1929 to 2003) show that the baseline for amphibian diversity in the Zululand region is a minimum of 52 species across 11 families and 21 genera. Species distribution extrapolated from these historical accounts show that 42 of the 52 frog species have been recorded inside NGR (Table 2.3). According to historic records NGR harbours at least 58% of the 73 species known to occur in KZN. Of the 42 species historically recorded within the reserve, 27 were detected in this study through both passive and active sampling methods. Prior to this study, between April 2013 and February 2014, Netherlands (2014) recorded 30 frog species within NGR. One of the species recorded in this study, *Kassina maculate,* was recently moved to the genus *Phlyctimantis* (see Portik and Blackburn 2016; Du Preez and Carruthers 2017). Two new species, *B. carruthersi* and *B. passmorei*, which occur in the Zululand region were described after completion of sampling for this study (Minter et al 2017). Of the two recently described species only *B. passmorei* was found inside NGR. Zululand frog diversity is thus updated to 54 species across 22 genera and the NGR's frog diversity is updated to 43 species. The ten species historically excluded from NGR were not recorded in this study (Table 2.3).

Table 2.3: Historical versus current amphibian diversity inside Ndumo Game Reserve.

	Zululand Frog Species	**Frog species expected inside NGR (Historical)**	**Frog species detected inside NGR (Current)**
	Arthroleptidae		
01	*Arthroleptis stenodactylus*	√	
02	*Arthroleptis walhbergii*	X	
03	*Leptopelis mossambicus*	√	√
04	*Leptopelis natalensis*	X	
	Breviceptidae		
05	*Breviceps adspersus*	√	√
06	*Breviceps bagginsi*	X	

Table 2.3 continued			
07*	*Breviceps carruthersi*		
08	*Breviceps mossambicus*	√	
09*	*Breviceps passmorei*		sp. nov.
10	*Breviceps sopranus*	X	
	Bufonidae		
11	*Poyntonophrynus fenoulheti*	√	
12	*Schismaderma carens*	√	√
13	*Sclerophrys capensis*	√	
14	*Sclerophrys garmani*	√	√
15	*Sclerophrys gutturalis*	√	√
16	*Sclerophrys* pusilla	√	√
	Hemisotidae		
17	*Hemisus guttatus*	X	
18	*Hemisus marmoratus*	√	√
	Hyperoliidae		
19	*Afrixalus aureus*	√	√
20	*Afrixalus delicatus*	√	√
21	*Afrixalus fornasinii*	√	
22	*Hyperolius argus*	√	
23	*Hyperolius marmoratus*	√	√
24	*Hyperolius pickersgilli*	X	
25	*Hyperolius poweri*	√	
26	*Hyperolius pusillus*	√	√
27	*Hyperolius semidiscus*	X	
28	*Hyperolius tuberilinguis*	√	
29+	*Phlyctimantis maculatus*	√	√
30	*Kassina senegalensis*	√	√
	Microhylidae		
31	*Phrynomantis bifasciatus*	√	√

Table 2.3 continued

	Phrynobatrachidae		
32	*Phrynobatrachus acridoides*	√	√
33	*Phrynobatrachus mababiensis*	√	√
34	*Phrynobatrachus natalensis*	√	√
	Ptychadenidae		
35	*Hildebrandtia ornata*	√	√
36	*Ptychadena anchietae*	√	√
37	*Ptychadena nilotica*	√	
38	*Ptychadena mossambica*	√	√
39	*Ptychadena oxyrhynchus*	√	
40	*Ptychadena porosissima*	X	
41	*Ptychadena taenioscelis*	√	
	Pipidae		
42	*Xenopus laevis*	√	
43	*Xenopus muelleri*	√	√
	Pyxicephalidae		
44	*Cacosternum boettgeri*	√	√
45	*Cacosternum nanum*	√	√
46	*Cacosternum striatum*	X	
47	*Amietia delalandii*	√	√
48	*Pyxicephalus edulis*	√	
49	*Strongylopus fasciatus*	√	
50	*Strongylopus grayii*	X	
51	*Tomopterna cryptotis*	√	√
52	*Tomopterna krugerensis*	√	√
53	*Tomopterna natalensis*	√	
	Rhacophoridae		
54	*Chiromantis xerampelina*	√	√
	* = Newly described species. + = Genus changed from *Kassina* to *Phlyctimantis.*		

2.3.2 Current frog diversity at Ndumo Game Reserve: Results from passive sampling

A marginally higher number of species were detected through active sampling in comparison to passive sampling. Twenty-three species were recorded through passive sampling of various sites inside NGR (Table. 2.4); this accounted for 55% of frog species that were expected to occur within the reserve. These findings represent a consolidation of results from the different passive sampling techniques employed in this study.

Table 2.4: Ndumo Game Reserve frog species detected through passive sampling.

	NGR Frog Species	**Sampling Method**		
		PAM	**Pitfall**	***Xenopus* traps**
	Arthroleptidae			
01	*Leptopelis mossambicus*	√		
	Breviceptidae			
02	*Breviceps adspersus*	√		
	Bufonidae			
03	*Sclerophrys garmani*	√		
04	*Sclerophrys gutturalis*	√		
05	*Sclerophrys* pusilla	√		
	Hemisotidae			
06	*Hemisus marmoratus*	√		
	Hyperoliidae			
07	*Afrixalus aureus*	√		
08	*Afrixalus delicatus*	√		
09	*Hyperolius marmoratus*	√		
10+	*Phlyctimantis maculatus*	√		
11	*Kassina senegalensis*	√		
	Microhylidae			
12	*Phrynomantis bifasciatus*	√	√	
	Phrynobatrachidae			
13	*Phrynobatrachus mababiensis*	√	√	
14	*Phrynobatrachus natalensis*	√		

Table 2.4 continued				
	Ptychadenidae			
15	*Hildebrandtia ornata*		√	
16	*Ptychadena anchietae*	√	√	
17	*Ptychadena mossambica*	√	√	
	Pipidae			
18	*Xenopus muelleri*			√
	Pyxicephalidae			
19	*Cacosternum boettgeri*		√	
20	*Cacosternum nanum*	√		
21	*Tomopterna cryptotis*	√		
22	*Tomopterna krugerensis*		√	
	Rhacophoridae			
23	*Chiromantis xerampelina*	√		
+ = Genus changed from *Kassina* to *Phlyctimantis.*				

A total of 19 species were recorded using Song Meters. Passive sampling through pitfall traps and *Xenopus* traps detected eight species. Pitfall traps set at forest sites did not detect any frogs while pitfall traps at Balemhlanga wetland and Ziphosheni pan detected seven species. The *Xenopus* traps only detected one species. Frogs collected through pitfall traps were mostly ground-dwelling species, while the *Xenopus* traps only detected aquatic frogs. Frogs of all habits apart from aquatic species were detected through the use of Song Meters. Two of the 23 species detected through passive sampling, *S. pusilla* and *P. maculatus*, were not detected through active methods.

2.3.3 Current frog diversity at Ndumo Game Reserve: Results from active sampling

Of the 42 frog species historically occurring within NGR, 25 were recorded through active sampling methods (Table. 2.5), thus accounting for 60% of species historically recorded in the reserve. Some species were detected through more than one active sampling method. The results are a combination of species accounts obtained from terrestrial searches, visual encounter surveys, MCS, and dip netting. The newly described *B. passmorei* was also detected through active sampling by Minter et al (2017).

Table 2.5: Ndumo Game Reserve frog species detected through active sampling.

	Zululand Frog Species	**Sampling Method**	
		Terrestrial search, Visual encounter surveys and MCS	**Dip Netting**
	Arthroleptidae		
01	*Leptopelis mossambicus*	√	
	Breviceptidae		
02	*Breviceps adspersus*	√	
	Bufonidae		
03	*Schismaderma carens*	√	
04	*Sclerophrys garmani*	√	
05	*Sclerophrys gutturalis*	√	
	Hemisotidae		
06	*Hemisus marmoratus*	√	√
	Hyperoliidae		
07	*Afrixalus aureus*	√	√
08	*Afrixalus delicatus*	√	
09	*Hyperolius marmoratus*	√	
10	*Hyperolius pusillus*	√	
11	*Kassina senegalensis*	√	√
	Microhylidae		
12	*Phrynomantis bifasciatus*	√	√
	Phrynobatrachidae		
13	*Phrynobatrachus acridoides*	√	

Table 2.5 continued			
14	*Phrynobatrachus mababiensis*	√	√
15	*Phrynobatrachus natalensis*		√
	Ptychadenidae		
16	*Hildebrandtia ornata*	√	√
17	*Ptychadena anchietae*	√	√
18	*Ptychadena mossambica*	√	
	Pipidae		
19	*Xenopus muelleri*	√	√
	Pyxicephalidae		
20	*Cacosternum boettgeri*	√	
21	*Cacosternum nanum*		√
22	*Amietia delalandii*	√	
23	*Tomopterna cryptotis*	√	√
24	*Tomopterna krugerensis*	√	
	Rhacophoridae		
25	*Chiromantis xerampelina*	√	√

Terrestrial searches, visual encounter surveys, and MCS accounted for 24 species collectively. Thirteen species were detected through dip netting. Five of the 25 species recorded through active sampling, *H. pusillus*, *S. carens*, *P. acridoides* and *A. delalandii*, were not detected through passive sampling.

2.4 Discussion

2.4.1 Amphibian Diversity at Ndumo Game Reserve

The number of species detected through active sampling is marginally higher than the number recorded through passive sampling. A difference of two species between two sampling alternatives does not provide definitive evidence of one sampling mode being more efficient than the other, nor does it provide grounds to pit the two against each other. However, a closer inspection of the results gained through the two sampling methods reveals the importance of using multiple methods. Of the 27 frog species recorded in NGR, two species could only be detected with passive sampling, while four species could only be detected using active sampling methods. The rest of the species were detected through both passive and active sampling methods. This confirms the need to use multiple survey methods to reduce the chance of non-detection. In the case of the two terrestrial sites where no species were recorded, PAM may have shown a presence of species, but it was never used. Passive acoustic monitoring has proved to be a valuable tool for sampling without influencing natural behaviour of focal species and causing minimal damage to the site being sampled. It is also a safe monitoring tool for the researchers as it allows data collection in areas where any other form of sampling would have been risky due to presence of dangerous animals.

MacKenzie et al (2002) mention that imperfect detection is inherent of all wildlife monitoring techniques. This may result from climatic variables, observer error or disturbance, and even aspects of frog biology that are beyond the observer's control. Biological features could include seasonal activity and acoustic properties of advertisement calls. There was a non-detection of 15 out of 42 species historically detected at NGR. A myriad of reasons could be contributing to this non-detection. Of these reasons, prevailing climatic conditions are among the main determinants for non-detection as anuran biology is closely tied to moisture levels. The 43^{rd} species recently found to occur inside NGR, which is the newly described *B. passmorei* (Minter et al 2017), was also not detected during sampling for this study. Although *B. adspersus* has been indicated to occur in the NGR, the possibility exists that these specimens in fact belong to the recently described and cryptic *B. passmorei* (see Minter et al 2017). The possibility of co-occurrence of *B. adspersus* and *B. passmorei* cannot be excluded and requires an in-depth investigation.

This study was carried out during a period when South Africa was experiencing one of its worst droughts in recorded history (Rautenbach 2016; Miller et al 2017). Drought conditions are unfavourable for frogs and thus decreases their activity (Cayuela et al 2016). The reserve covers a large area and cannot be thoroughly surveyed through active sampling due to time constraints, sites being inaccessible due to safety factors or remoteness. Long-term monitoring through PAM was only carried out at two of the sampling sites within the reserve, and these may not have been suitable microhabitats for all 43 NGR frog species thus resulting in non-detection. An extreme scenario to explain non-detection is that pressure from anthropogenic factors may have led to the extinction of species from the reserve. Species that are historically excluded from NGR yet occur in the Zululand region were not recorded in this study. This non-detection adds further validity to historical records, provides evidence that the distribution range of those species does not include NGR, and emphasizes the importance of long-term monitoring.

2.4.2 Amphibian diversity and KwaZulu-Natal's rapidly increasing human population

The IUCN Red List status of each frog species that occurs within NGR, known from both historical accounts and the current study, falls in the 'Least Concern' category (see IUCN 2017b). If international amphibian diversity trends (see Blaustein and Kiesecker 2002; Collins and Storfer 2003; Hof et al 2011) are anything to go by and considering that at least 69 South African frog species are experiencing range contractions (Botts et al 2012), then the conservation status of some of the NGR frogs may soon change due to KwaZulu-Natal's rapidly increasing population. Human population estimates for KZN show an increase from 8 572 302 people in 1996, to 10 267 300 in the year 2011, and 11 074 800 in 2017 (see Stats SA 2014; Stats SA 2017). Anthropogenic factors have resulted in extensive habitat loss in the province. Between 1994 and 2011 an average 1.2% of natural habitat was lost annually, leading to 73% of KZN that was available as natural habitat in 1994 being reduced to 53% in 2011 (Figure 2.5), and further projected to decrease to 45% by 2050 (Jewitt et al 2015).

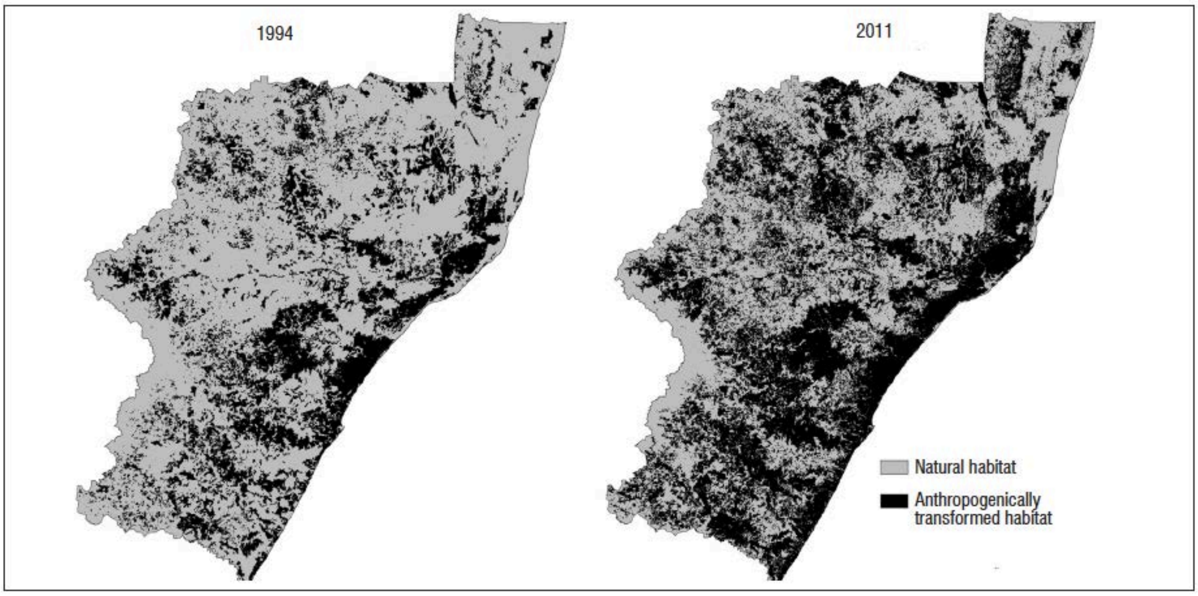


Figure 2.5: Habitat loss in KwaZulu-Natal from 1994 to 2011 (Jewitt et al 2015).

Human population size in KZN exhibits a negative relationship with available natural habitat; as the number of people living in the province increases the proportion of KZN's natural habitat decreases. The percentage of natural habitat (Jewitt et al 2015) and human population size (see Stats SA 2012; 2014; 2017) in KZN have a correlation coefficient close to -1 (Table 2.6). This denotes a strong downhill linear relationship; and suggests that the provinces rapidly increasing population contributes to decreasing natural habitats.

Table 2.6: Correlation between natural habitat and human population size in KwaZulu-Natal. Estimate of remaining natural habitat extrapolated from Jewitt et al (2015). KwaZulu-Natal human population estimates obtained from Stats SA (2012; 2014; 2017)

Year	Natural Habitat (%)	Human Population Size	Frog Species
1994	73,00%	Data Not Available	
1995	72,00%	Data Not Available	
1996	71,00%	8417021,00	
2001	65,00%	9426017,00	
2003	63,00%	9761032,00	
2004	61,00%	9835710,00	
2011	53,00%	10819130,00	42,00
2014	52,00%	10694400,00	
2017	51,00%	11074800,00	30,00
2050	45,00%	Data Not Available	27,00
	rs = -0,9876956		

Amphibian monitoring data for NGR is not sufficient enough to allow for a thorough investigation into how KZN's human-activity-induced habitat loss affects the reserve's frog diversity. A preliminary investigation using available monitoring data suggests a possible decline in NGR's frog diversity. However, drought conditions may have also contributed to non-detection of species. The correlation coefficient between percentage of natural habitat remaining in KZN and frog diversity (i.e. number of frog species) at NGR hints at a strong upward linear relationship (Table 2.7). This coefficient is calculated with minimal amphibian diversity data due to lack of monitoring but still suggests a relationship similar to global trends of amphibian diversity declining with a decrease in availability of natural habitats.

Table 2.7: Correlation between natural habitat in KwaZulu-Natal and amphibian diversity inside Ndumo Game Reserve. Estimates of remaining natural habitat extrapolated from Jewitt et al (2015). Amphibian diversity data extrapolated from Minter et al (2004), Netherlands (2014), and the current study. Estimates of remaining natural habitat extrapolated from Jewitt et al (2015).

Year	Natural Habitat (%)	Frog Species
1994	73,00%	Data Not Available
1995	72,00%	Data Not Available
1996	71,00%	Data Not Available
2001	65,00%	Data Not Available
2003	63,00%	Data Not Available
2004	61,00%	42,00
2011	53,00%	Data Not Available
2014	52,00%	30,00
2017	51,00%	27,00
2050	45,00%	Data Not Available
		rs = 0,995082099

Habitat loss has resulted in biodiversity loss and a decrease in species' populations (O'Connor and Kuyler, 2009). It poses a threat to NGR's amphibian diversity and KZN's biodiversity as a whole. A comparison of NGR amphibian diversity with KZN's human population size and proportion of natural habitat over time hints at a possible decline of NGR's frog species due to habitat loss resulting from anthropogenic factors (Figure 2.6). In figure 2.6 a trendline is used to predict future changes to variables based on past and current trends, and it suggests future decreases in amphibian diversity while human population continues to increase. The association between the three factors is however weak as this finding is based only on a preliminary investigation using data of differing timescales and resolution. For a more definitive statement on the effects of human population pressure on NGR's amphibian diversity, natural habitat decline and changes in human activity within the reserve would have to be also studied.

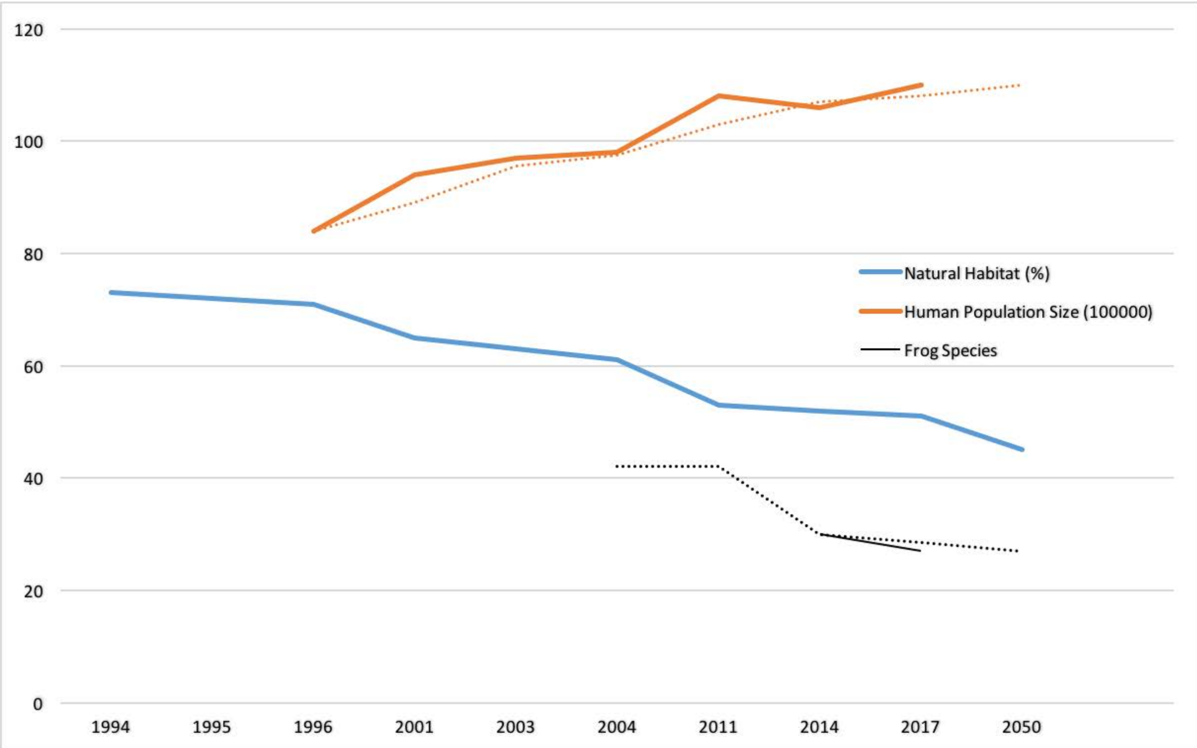


Figure 2.6: Relationship between Ndumo Game Reserve's amphibian diversity, available natural habitat and human population size in KwaZulu-Natal. Amphibian diversity data extrapolated from Minter et al (2004), Netherlands (2014), and the current study. Estimates of remaining natural habitat extrapolated from Jewitt et al (2015). KwaZulu-Natal human population size estimates obtained from Stats SA (2012; 2014; 2017**)**

There is also a possibility of NGR's reduced amphibian diversity in comparison to historical records being a result of imperfect detection in the current study and not being related to habitat loss. Inaccuracies in amphibian species detection in this study could have resulted from persistent drought conditions during sampling. However, this explanation does not hold true for the study by Netherlands (2014) where sampling was conducted before the onset of drought conditions and over a longer period. Some of the PAM for this study from April 2013 to April 2014 also occurred before onset of drought conditions.

2.5 Conclusion

The high number of amphibian species inside the reserve make it a biodiversity hotspot in the South African context and thus a suitable conservation area for the country's amphibian diversity. The amphibian diversity detected in this study is lower than the NGR's baseline established through historical records and this is a cause for concern. Another cause for concern is that a prior study by Netherlands' (2014) also recorded amphibian diversity lower than the established baseline at NGR, and this current study recorded an even lower diversity than the Netherlands (2014) results. This progressive decline in recorded amphibian diversity correlates with increases in KZN's human population and natural habitat loss (Figure 2.5; Table 2.6–2.7).

The association is however weak as there is a difference in the resolution of data used when investigating correlation. Netherlands (2014) compared amphibian diversity inside NGR and outside the reserve and found lower diversity at sampling sites outside the reserve impacted by human activity. This finding by Netherlands (2014) further hints at frog diversity in KZN being negatively affected by the province's increasing human population. Two of the most important criteria for a water body to make it a suitable site for frogs are a degree of vegetation cover along the periphery and unpolluted water. Trampling of peripheral vegetation and organic and chemical pollution of water by livestock and spraying of crops often degrade water quality to the extent that it becomes unsuitable to sustain amphibian diversity.

The abovementioned results, though preliminary, highlight a need for increased amphibian biodiversity monitoring in order to better understand long-term diversity fluctuations and plan accordingly for mitigation of amphibian declines.

Chapter 3: Habitat Usage by Amphibians at Ndumo Game Reserve

3.1 Introduction

A contributory factor to the survival of amphibians since their emergence is how they utilise habitats. Investigations into Cretaceous extinction survivorship suggest that taxa which made use of freshwater habitats, including amphibians, were less threatened by extinction in comparison to their terrestrial and marine counterparts (Robertson et al 2013). Some of the amphibian diversification following this extinction event was most likely enhanced by the increase of angiosperms as 82% of recently diverged amphibian species live in forest microhabitats (Roelants et al 2007). This rise of angiosperms provided a variety of microhabitats for amphibians to inhabit.

The highest diversity of amphibians occurs in tropical and sub-tropical regions where productivity is high, and a high diversity of microhabitats are available for utilisation (Figure 3.1). In South Africa, such microhabitat variety is found in the north-eastern part of the country, where the highest frog diversity also occurs (see Alexander et al 2004; Measey 2011). The above provides evidence of amphibian biodiversity being linked to microhabitat diversity and not just the mere availability of a habitat. Land use change is a major contributor to the reduction of faunal biodiversity (Collins 2003) as it reduces both the diversity and percentage of available microhabitats. This decrease in the size and variety of microhabitats ultimately leads to a decrease in species that utilise them.

Amphibians exhibit a preference for tropical and sub-tropical habitats at a macro-scale (Figure 3.1) but at a micro-scale their preference differs as each species prefers certain microhabitats (see Minter et al 2004; du Preez and Carruthers 2017). This chapter explores microhabitat preference of Ndumo Game Reserve's (NGR) amphibian community and other aspects of habitat utilisation. This preference of habitats can be used to explain exclusion of species from habitats or localities. Other factors responsible for exclusion include barriers to dispersal for species, physiological barriers, or competitive exclusion through interspecific relationships. Globally, amphibians are excluded from extreme northern latitudes and most oceanic islands (Vitt and Caldwell 2009). Lethal freezing is a risk due to the cold climate of the extreme northern latitudes, but there are a few North American frog species that are known to survive below zero temperatures in winter (Layne et al 1995). The few exceptions to the exclusion of amphibians from oceanic islands are believed to have colonised islands from the mainland through a chance event (Measey et al 2007; Bell et al 2015), or through human-assisted dispersal (Plenderleith 2015). Some of the key factors in amphibian exclusion from oceanic islands is desiccation as a result of saltwater, and very few animals can survive the long-distance overwater dispersal from the mainland to colonise an island. Their physiological inability to adapt to saltwater has largely excluded frogs from estuarine and marine habitats globally (Vitt and Caldwell 2009).

In addition to exclusion from extreme northern latitudes and most oceanic islands, amphibian exclusion or low diversity also coincides geographically with deserts (Figure 3.1). At a continental scale, Africa has amphibians excluded from parts of the Sahara Desert while the Namib Desert and other parts the Sahara have a low diversity of frog species adapted to survive the extreme conditions. A stark contrast to these deserts is found in tropical areas such as West Africa which contain a variety of microhabitats and a more suitable climate that result in higher amphibian diversity.

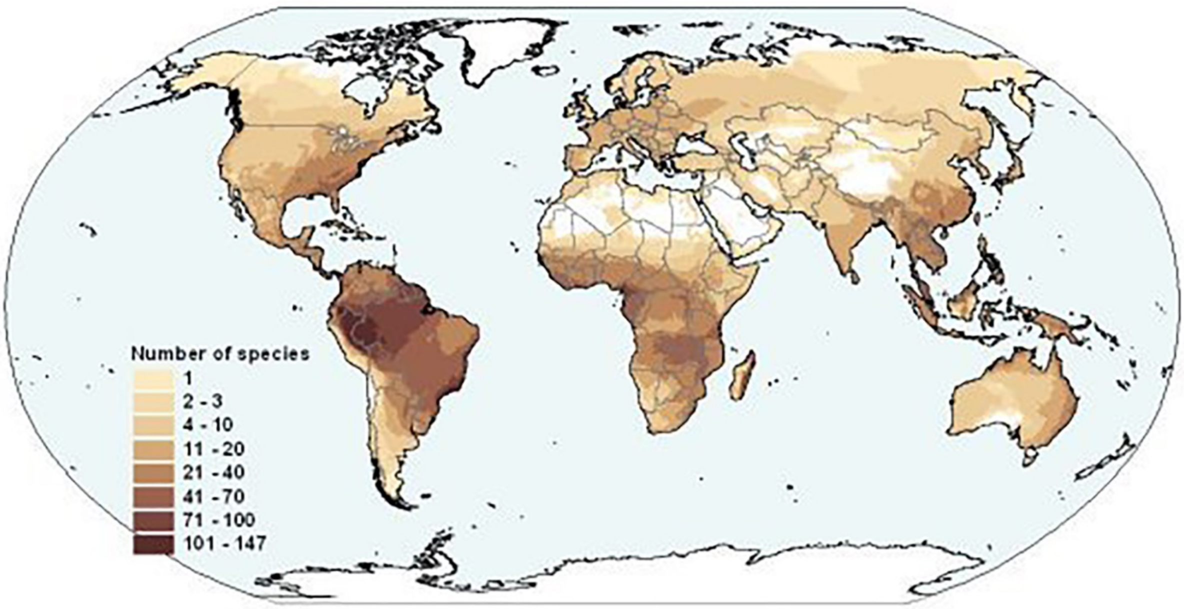


Figure 3.1: Global patterns of amphibian diversity (IUCN 2016).

In the South African context, the highest diversity occurs in the north-eastern corner of the country, while the harsher climate on the western side of the country results in lower diversity of species. Species that occur in the north-eastern region are sometimes excluded from places within this region. This applies to frog species found in the Zululand region, but their distribution range falls outside NGR. Eleven Zululand species, including the newly described *B. carruthersi* (see Minter et al 2017), were not recorded inside NGR during this study and a previous frog diversity study by Netherlands (2014).

This non-detection validates historical records and provides evidence that the distribution range of those species does not include NGR. It also leads to curiosity as to why these species are excluded from NGR when the reserve at face value seems to have similar microhabitats to those utilised by the excluded species in other parts of the Zululand region. Climate is unlikely to be a factor in this exclusion as NGR and Zululand fall within the same climatic region. To understand the exclusion of certain Zululand frog species from NGR, this chapter investigates the contribution of microhabitat suitability and dispersal barriers as factors of exclusion.

3.2 Materials and Methods

3.2.1 Collection of habitat usage data

A combination of active and passive sampling methods was used to ascertain the presence of frogs at the various NGR microhabitats (as discussed in Chapter 2). Manual call surveys (MCS), terrestrial searches, visual encounter surveys, dip netting, Passive Acoustic Monitoring (PAM), *Xenopus* traps, and drift fence pitfall traps (pitfall traps) were used to survey frog diversity. Sampling covariates or environmental variables were recorded at each of the sites surveyed for this study. These covariates are necessary for explaining species' variation with environmental variables (Dorcas et al 2009). They also aid in investigating how species utilise their habitats. Surveys of NGR amphibian diversity began with an assessment of habitats to determine their suitability for frogs and to classify them into different microhabitat types (Table. 2.1) as defined by du Preez and Carruthers (2009).

The location of each site was recorded and its coordinates captured using the World Geodetic System 1984 (WGS84) datum. These coordinates also assisted in categorising sites into five vegetation types (Figure 3.2; Table 3.1) according to the Vegetation Map of South Africa, Lesotho and Swaziland (SANBI 2012). This was done by loading a vector dataset of this vegetation map onto Google Earth Pro (Google Inc.) which served as a Geographic Information System (GIS) viewer to cross-reference site coordinates with vegetation type (Figure 3.2).

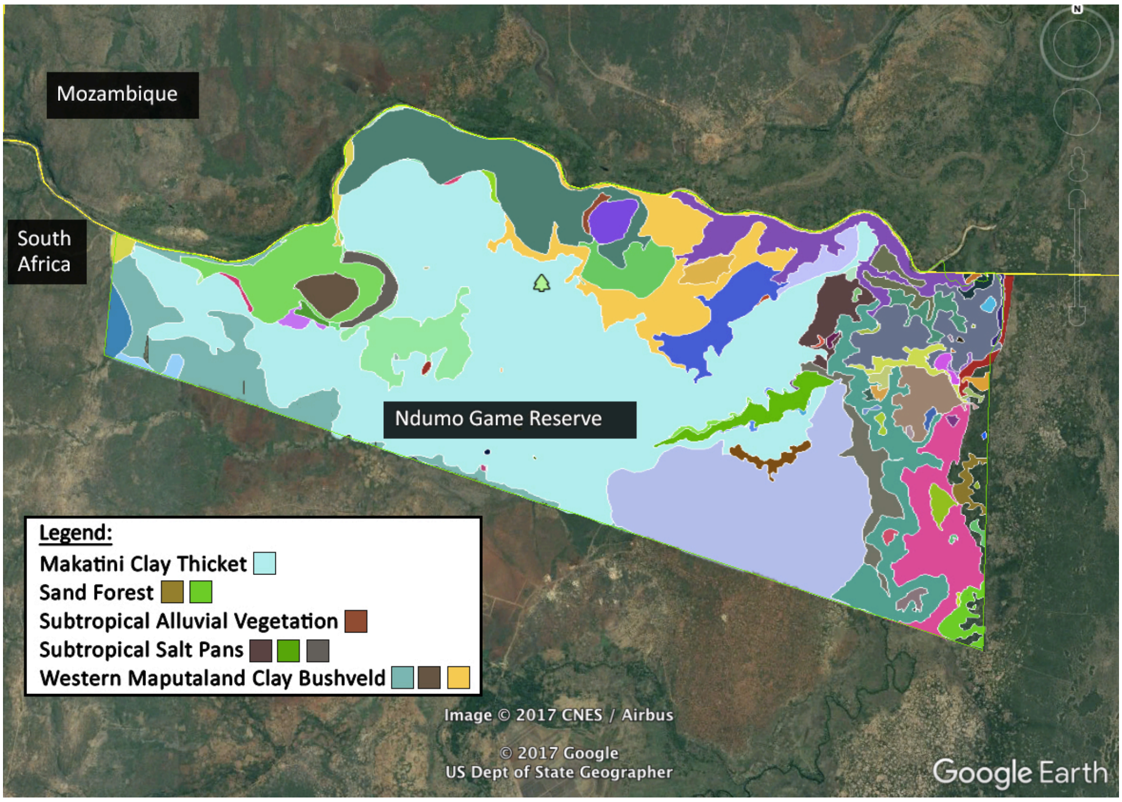


Figure 3.2: The different vegetation types at sites sampled within Ndumo Game Reserve as mapped by SANBI (2012).

Table 3.1: Vegetation types at Ndumo Game Reserve frog habitats as defined by SANBI (2012).

Vegetation Type	Description
Makatini Clay Thicket	**Biome:** Savanna. **Vegetation unit:** Lowveld. Comprises of mixed, simple-leaved short bushland and thicket with emergent trees and dense shrub layer. **Soils:** melanic clays and clay loams.
Sand Forest	**Biome:** Savanna. **Vegetation unit:** Sand forest. **Vegetation features:** from dense thickets to tall forests. Shrub layer well-developed, ground layer poorly developed. **Soils:** acidic with very little clay.

Table 3.1 continued	
Subtropical Alluvial Vegetation	**Biome:** Savanna. **Vegetation unit:** Alluvial vegetation. **Vegetation features:** macrophytes, marginal reed belts, flooded grasslands, ephemeral herblands and riverine thickets. **Soils:** sandy to loamy soils.
Subtropical Salt Pans	**Biome:** Savanna. **Vegetation unit:** Inland Saline Vegetation. **Vegetation features:** reed beds, low herblands and macrophytic floating vegetation. **Soils:** Cenozoic alluvium, sand and calcrete.
Western Maputaland Clay Bushveld	**Biome:** Savanna **Vegetation unit:** Lowveld. **Vegetation features:** mixed but mainly compound leaved short woodlands and wooded grasslands. **Soils:** sandy clay loam to clay, and calcimorphic soils.

In addition to determining the vegetation type of a particular habitat, the various plants utilised by frogs were documented and each frog species' usage of a particular plant was recorded by taking a photograph with a Canon EOS 650D camera. The plants' stem, leaves, flowers, and fruit were also photographed as diagnostic characters. These diagnostic traits were used to identify the plants to genus level, using the Guide to Plant Families of Southern Africa by Koekemoer et al (2014). Plants that had not yet blossomed or did not have any fruit available were only identified up to family level to reduce the chance of misidentification due to the lack of an important diagnostic trait.

Ambient temperature and measurements of water variables including conductivity and total dissolved solids were also recorded as sampling covariates. Ambient temperature was recorded using a thermometer, and the Song Meters (Song Meter^{TM} model SM2 and SM3; Wildlife Acoustics Inc., Concord, Massachusetts) used for PAM are also equipped with an ambient temperature sensor which records temperature along with advertisement call data. Water variables were measured at each site on a weekly basis from 22 November 2016 to 14 December 2016. This was done using a Handheld Multiparameter Instrument (YSI 556 MPS; YSI Inc. / Xylem Inc., Yellow Springs, Ohio). This instrument was used to measure the water's temperature, conductivity, total dissolved solids, percentage of dissolved oxygen, air saturation, and PH.

Pitfall traps were setup in a longitudinal manner and used over a period of five days to investigate how frogs use habitats in response to changes in water availability (Figure 3.3). Pitfall drift fences served as a barrier separating a site with water from a site without water. At each end of the drift fences, there were two five litre buckets buried on both sides. These buckets caught frogs being channelled from different sides of the pitfall trap to establish the direction they were moving when they encountered the drift fence. This 2 m long and 30 cm high drift fence was buried (~5 cm) in the ground, to ensure that no frogs could pass underneath. Two of these pitfalls were placed longitudinally between a section of Balemhlanga wetland (Figure 2.3: B) that was drying up and another section, which still held sufficient standing water. A third pitfall trap was placed longitudinally between the dry Ziphosheni pan (Figure 2.3: X) and the Balemhlanga floodplain (Figure 2.3: A), which still had standing water but was 890 m away.

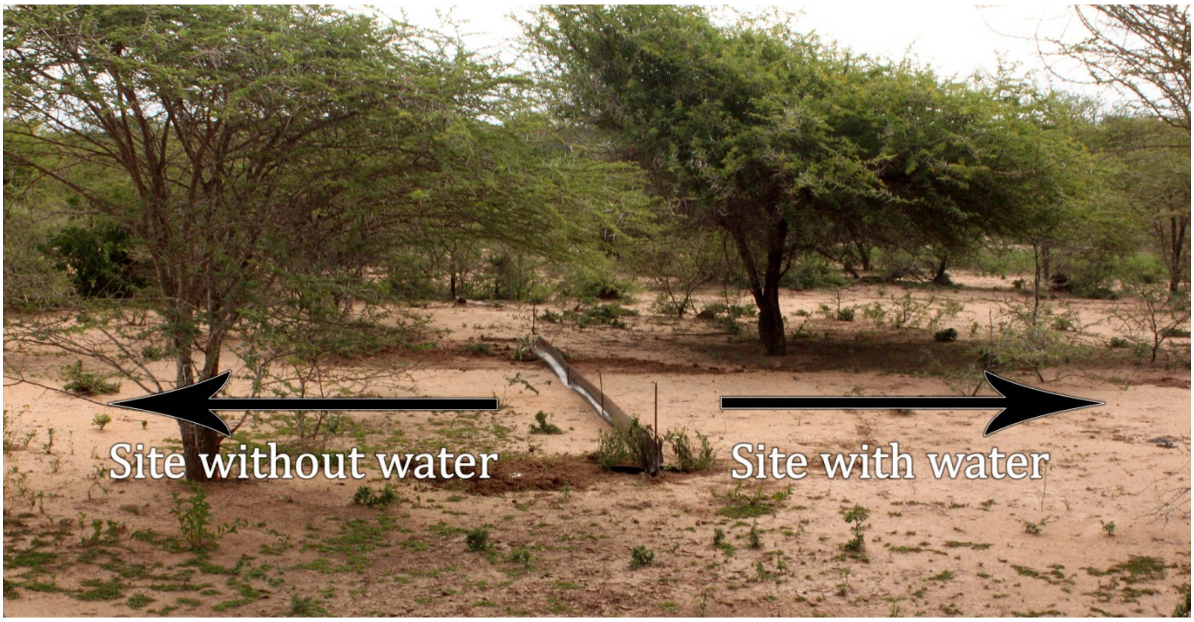


Figure 3.3: Longitudinal drift fence pitfall trap used to detect frog movement in response to water availability.

3.2.2 Exclusion of frogs from habitats within their distribution range

An extrapolation of distribution data from Minter et al (2004) shows that ten of the 52 frog species historically occurring in Zululand are excluded from NGR. Minter et al (2017) shows that one of the two recently described *Breviceps* species is excluded from NGR but it occurs within the greater Zululand region. This chapter investigates the possible causes of this exclusion. Furthermore, it accounts for the exclusion of frogs from microhabitats within NGR. To investigate the exclusion of 11 Zululand species from NGR, the study compared their known suitable microhabitats with microhabitats found inside NGR. The absence of suitable microhabitats would then provide a basis for exclusion. In cases where preferred microhabitats for a certain species were available inside NGR, yet the expected species was absent, the study investigated possible barriers to dispersal. The 42 species historically known to occur inside the reserve and the one recently described species found to occur inside NGR by Minter et al (2017) are also subject to exclusion. For this exclusion of species from microhabitats within NGR, the study investigated microhabitat-specific factors that may be responsible for this exclusion.

3.2.3 Variation of amphibian species with habitat and vegetation

Multivariate analysis was employed to investigate variation of NGR's amphibian species with microhabitat and vegetation type. This analysis was carried out using the CANOCO for Windows 4.5 program (Ter Braak and Šmilauer 2002). The variation in amphibian diversity is summarized using ordination methods. Choosing an appropriate ordination model to use requires running a detrended correspondence analysis (DCA) and using gradient length measures obtained from the DCA to assist in deciding whether to use linear or unimodal ordination methods (Lepš and Šmilauer 2003). Linear ordination methods are based on a species response model where changes of species values along ordination axes are represented by straight lines, while unimodal ordination methods are used when data is heterogeneous and there is a lot of deviation of species from the assumed model of linear response (Lepš and Šmilauer 2003).

3.3 Results

3.3.1 Habitat preference

Frogs within NGR exhibited a preference for endorheic and palustrine sites. Twenty-four species were recorded at endorheic sites while a total of 15 species were recorded at palustrine sites (Figure 3.4: A; C). The number of species recorded at lacustrine, riverine, and terrestrial microhabitats was 13, 11, and 0 respectively. The more preferred microhabitats, endorheic and palustrine, are characterised by shallow water, emergent vegetation and vegetated banks. The endorheic microhabitats additionally contain overhanging trees. No frogs were detected on the forest floor. The above microhabitats fall within five vegetation types (Figure 3.2). Frog activity was detected at four of these vegetation types (Figure 3.4: E–H).

Plotting species richness against vegetation type shows that the highest number of species occurred at Makatini Clay Thicket and Western Maputaland Clay Bushveld vegetation types (Figure 3.4: E; H). Twenty-five and 20 frog species were recorded at these vegetation types respectively. The lowest number of species was recorded at Subtropical Alluvial Vegetation and Sand Forest vegetation types. The most frequently recorded amphibian species at NGR sampling sites were *C. xerampelina*, *P. mababiensis*, and *P. anchietae* (Figure 3.4; Table 3.6)

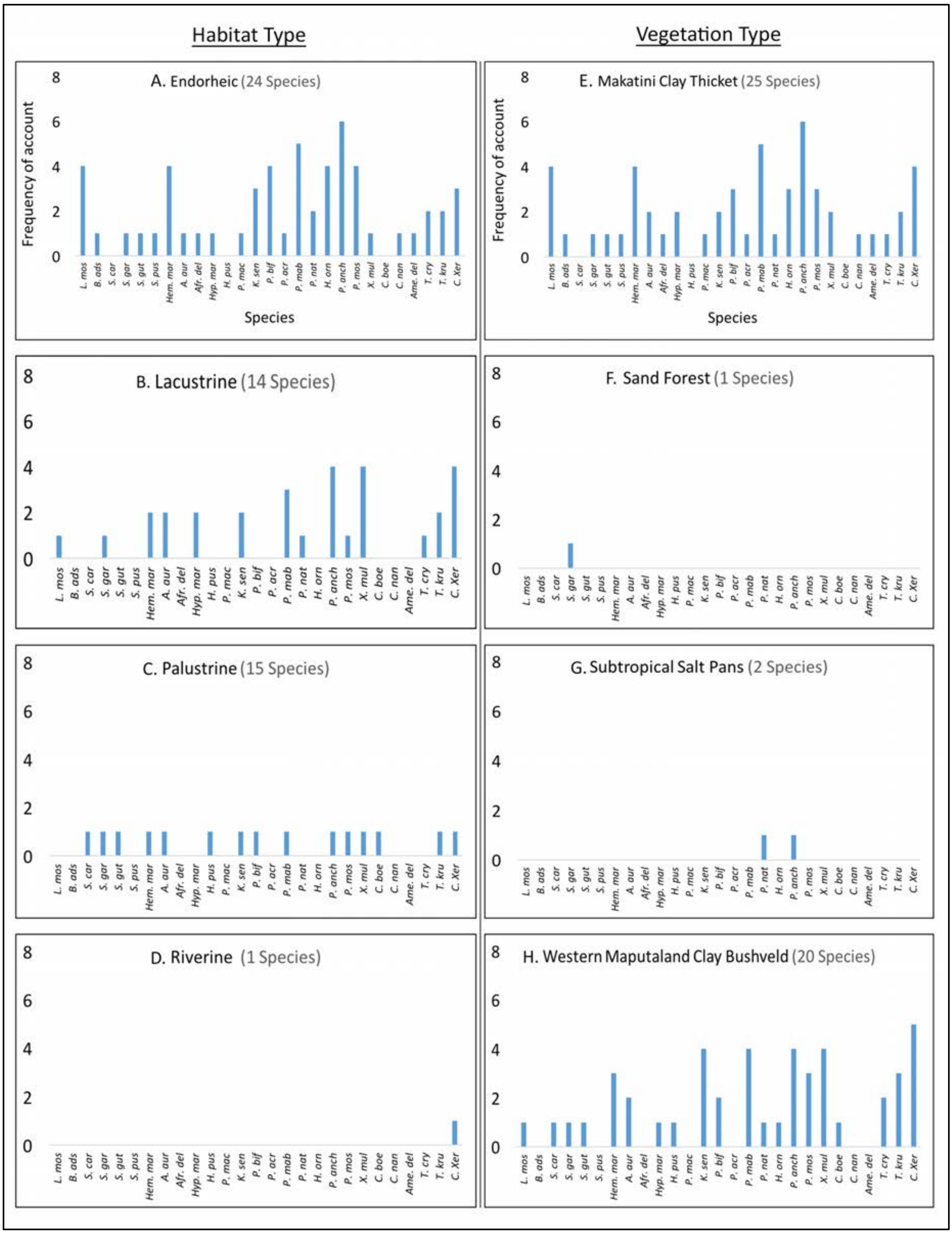


Figure 3.4: Amphibian species count and frequency of account at the five habitat and vegetation types sampled within Ndumo Game Reserve. The frequency of species account is based on 8 sampling occasions for each of the microhabitat and vegetation types. Species accounts from Terrestrial microhabitat and Subtropical Alluvial Vegetation are omitted as no frogs were detected.

Ambient temperatures at NGR sampling sites ranged between 7.9 and 45 °C. The water variables measured at these microhabitats varied (Figure 3.5). The lowest temperature water temperature was 23 while the highest was 37.9 °C (Table 3.2). Dissolved oxygen was found to be as low as 1.2% at some of the sampling sites utilised by frogs.

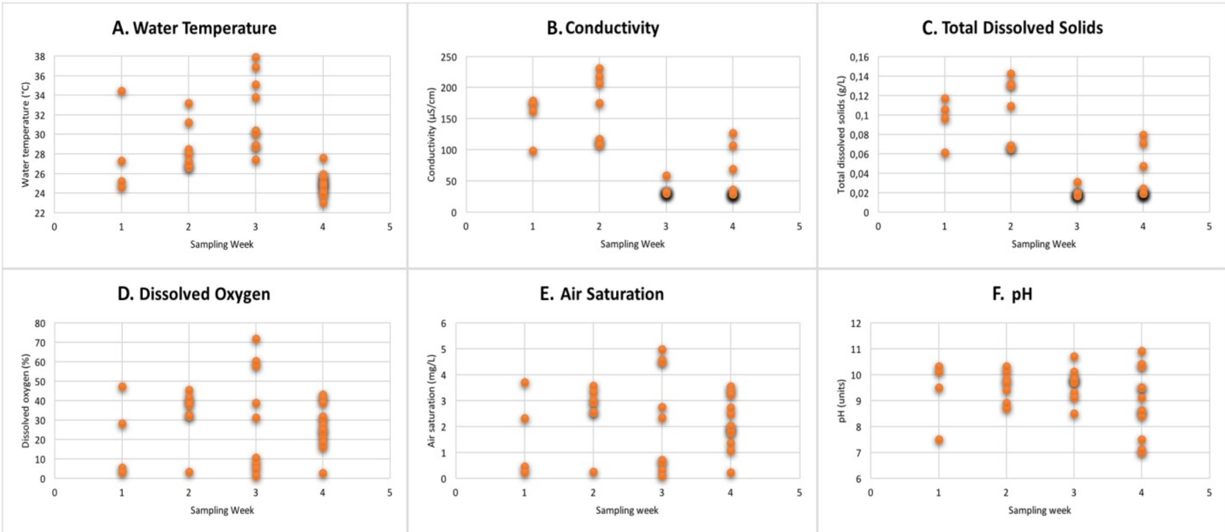


Figure 3.5: A summary of water variables at Ndumo Game Reserve frog habitats as recorded during active sampling from 22 November 2016 to 14 December 2016.
A – Water temperature (°C). **B** - Conductivity (µS/cm). **C** – Total dissolved solids (g/L). **D** - Dissolved oxygen (%). **E** - Air saturation (mg/L). **F** - pH (units).

The most notable difference between sampling sites with amphibian activity and sites without any recorded amphibian activity is pH and conductivity range. The pH measurements at sites with amphibian activity ranged between 7 and 11.3 while the pH at sites without frog activity ranged between 6.6 and 7.7 (Table 3.2). Similar to pH, conductivity measurements also had a lower range at sites without frog activity (30 µS/cm; 107 µS/cm) in comparison to sites with recorded frog activity (29 µS/cm; 231 µS/cm) (Table 3.2).

Table 3.2: Summary of water variables at Ndumo Game Reserve frog habitats as recorded during active sampling from 22 November 2016 to 14 December 2016.

Variable	**Sites with recorded frog activity.** $\bar{x}$ (range)	**Sites without recorded frog activity.** $\bar{x}$ (range)
Water temperature (°C)	28.4 (23; 37.9)	28.2 (23.7; 33.1)
Conductivity (µS/cm)	86 (29; 231)	46 (30; 107)
Total dissolved solids (g/L)	0.05 (0.02; 0.14)	0.29 (0.02; 0.08)
Dissolved oxygen (%)	27.9 (1.2; 71.8)	50.9 (16.2; 107.0)
Air saturation (mg/L)	2.17 (0.09; 4.96)	3.83 (1.25; 8.41)
pH (units)	9.5 (7.0; 11.3)	7.1 (6.6; 7.7)

3.3.2 Temporal habitat usage

All 27 frog species recorded in this study were found to be active at night. Eight of these, namely *C. xerampelina*, *H. ornata*, *Hyp. marmoratus*, *P. mababiensis*, *P. anchietae*, *P. mossambica*, *T. krugerensis*, *and X. muelleri*, were additionally recorded at daytime. Of the species encountered during the day, *C. xerampelina* and *Hyp. marmoratus* were the only dormant species observed (Figure 3.6: A–B). The remaining six species were active.

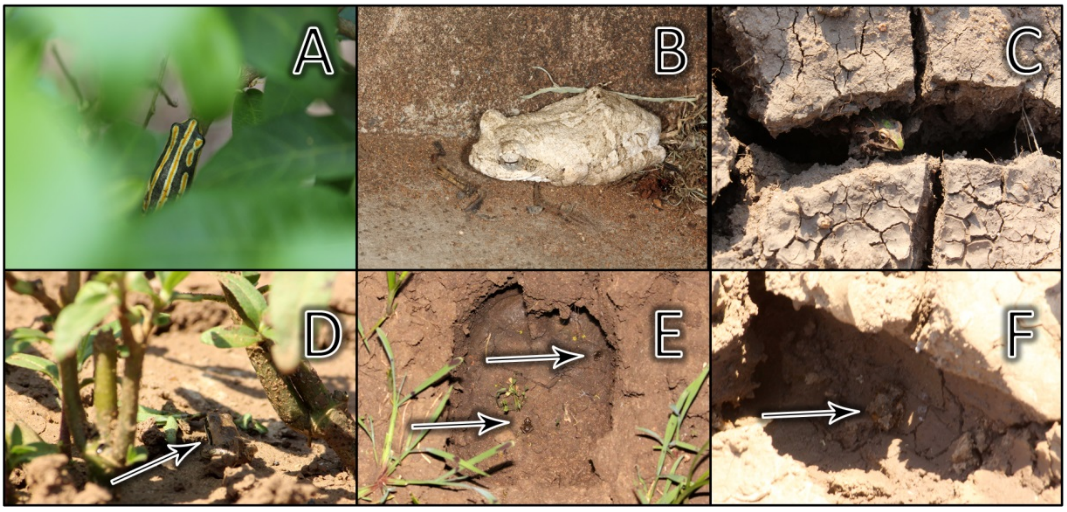


Figure 3.6: Frog species observed at daytime.
A – *Hyperolius marmoratus*: Dormant and sitting on cooler, heavily shaded parts of shrubs. **B** – *Chiromantis xerampelina*: Dormant with lightened skin colour. **C** – *Hildebrandtia ornata*: Hiding in cracks on the ground. **D** – *Ptychadena anchietae*: Using shade provided by vegetation. **E** – *Tomopterna krugerensis:* Using cooler depression in the ground left by a giraffe. **F** – *Phrynobatrachus mababiensis*: Using shade provided by warthog scrape marks.

These active species (except *X. muelleri*) were observed periodically taking refuge in the cooler parts of their habitats; shade of plants, cracks in the ground, and depressions left by large mammals (Figure 3.6: C-F). Poor water clarity made it difficult to observe how *X. muelleri* reacted to high ambient daytime temperatures.

3.3.3 Habitat usage linked to moisture availability

The three pitfall traps used to investigate how frogs respond to available moisture over a period of five days yielded results suggesting movement away from dry sites but not the complete abandonment of such sites. A total of 23 individuals from eight species were recorded moving from dry sites towards sites with water, while nine individuals from four species were detected moving towards dry sites (Table 3.3).

Table 3.3: Frog movement to and from dry microhabitats inside Ndumo Game Reserve.

Dry Site	Species moving from dry site	Count	Species moving toward dry site	Count
Balemhlanga Wetland				
	C. boetgerri	1		
	P. bifasciatus	1	*P. bifasciatus*	1
	P. anchietae	1	*P. anchietae*	1
	P. mossambica	4		
	T. krugerensis	11	*T. krugerensis*	5
Subtotal	5 Species	18	3 Species	7
Ziphosheni pan				
	H. ornata	1		
	L. mossambicus	1		
	P. mababiensis	1	*P. mababiensis*	2
	P. anchietae	1		
Subtotal	4 species	4	1 Species	2
Total	8 species	23	4 Species	9

3.3.4 Plant usage by genus

During active sampling, the following genera were observed to make minimal use of vegetation; *Amietia, Hemisus, Hildebrandtia, Kassina, Phrynomantis, Schismaderma, Sclerophrys,* and *Tomopterna. Hemisus* and *Hildebrandtia* occasionally used leaf litter for cover. Seven frog genera were recorded utilising at least 11 plant families (Table 3.4) within NGR. Three of the seven genera (*Phrynobatrachus, Ptychadena,* and *Cacosternum*) only used the lower parts of vegetation. Those that did make use of the upper parts of vegetation include *Afrixalus, Cacosternum, Chiromantis, Hyperolius, Leptopelis, Phrynobatrachus* and *Ptychadena*.

Table 3.4: Recorded plant utilisation by frogs at Ndumo Game Reserve, listed alphabetically by family.

	Frog genus	Plants used
	Arthroleptidae	
01	*Leptopelis*	- Apocynaceae (Milkweed). Genus: *Carissa*. - Cyperaceae (Sedges). Genus: *Cyperus*. - Poaceae (Grass family). Genus: *Brachiaria.*
	Hyperoliidae	
02	*Afrixalus*	- Amaryllidaceae (Clivia family). Genus: *Crinum*. - Asteraceae (Daisy family). - Cyperaceae (Sedge family). Genus: *Cyperus*. - Poaceae (Grass family). Genus: *Brachiaria.*
03	*Hyperolius*	- Celastraceae (Spike-thorn family). Genus: *Maytenus.* - Cyperaceae (Sedge family). Genera: *Cyperus* and *Isolepis*. - Poaceae (Grass family). Genus: *Brachiaria.*
	Phrynobatrachidae	
O4	*Phrynobatrachus*	- Cyperaceae (Sedge family). Genus: *Isolepis*.
	Ptychadenidae	
05	*Ptychadena*	- Amaryllidaceae (Clivia family). Genus: *Crinum.* - Asteraceae (Daisy family). - Cyperaceae (Sedge family). - Poaceae (Grass family). Genus: *Capechloa.*
	Pyxicephalidae	
06	*Cacosternum*	- Poaceae (Grass family).
	Rhacophoridae	
07	*Chiromantis*	- Amaranthaceae (Amaranth family). Genus: *Amaranthus.* - Anacardiaceae (Wild currant family). Genus: *Searsia.* - Asteraceae (Daisy family). - Fabaceae (Pea family). Genera: *Acacia* and *Schotia.* - Rhamnaceae (Buffalo-thorn family).

***Leptopelis* sp. vegetation utilization**

Leptopelis mossambicus either used trees or sedges as call sites. Their preferred call site on sedges, Cyperaceae (*Cyperus* sp.), was at the base of the plant. Their position on tall trees could not be ascertained as they were well concealed. Thus, the exact tree used as a call site could also not be identified. Juvenile *L. mossambicus* (Figure 3.7: A) were recorded on Apocynaceae (*Carissa* sp.), Cyperaceae (*Cyperus* sp.), and Poaceae (*Brachiaria* sp.).

***Afrixalus* sp. vegetation usage**

Afrixalus aureus used the leaves of Cyperaceae (*Cyperus* sp.), and Poaceae (*Brachiaria* sp.) as preferred call sites and at times their culms. They also used leaves of Asteraceae as call sites (Figure 3.7: C). These leaves were also used as mating sites. Amaryllidaceae (*Crinum* sp.) leaves were the only recorded call site for *A. delicatus* and no nests were recorded.

***Hyperolius* sp. vegetation usage**

Hyperolius marmoratus was observed during the day taking refuge in the cool, shaded stem of a Celastraceae shrub (*Maytenus* sp.) (Figure 3.6: A). At night-time, the species used the leaves and culms of Poaceae (*Brachiaria* sp.) and Cyperaceae (*Cyperus* sp.) as call sites without exhibiting a preference to either of the two (Figure 3.7: D). *Hyperolius pusillus* showed preference towards emergent Cyperaceae (*Isolepis* sp.).

***Phrynobatrachus* sp. plant usage**

Phrynobatrachus mababiensis were mostly recorded using the soil in their habitats. Their observed plant usage consisted of backing into the bases of Cyperaceae (*Isolepis* sp.) and using them as call sites (Figure 3.7: F).

***Ptychadena* sp. vegetation usage**

Species of this genus were mostly recorded on the wet soil around waterbodies. *Ptychadena anchietae, P. mossambica* juveniles took cover between the culms of Cyperaceae and Poaceae (*Capechloa* sp.) when disturbed. *Ptychadena anchietae* adults were noted sitting and calling with their vents pressed against the bases of Asteraceae and Amaryllidaceae (*Crinum* sp.) (Figure 3.7: G). This type of habitat usage is similar to that noted in *Phrynobatrachus*.

Cacosternum sp. plant usage

Cacosternum boettgeri was mostly noted on soil but occasionally found utilising Poaceae (Figure 3.7: E).

***Chiromantis* sp. vegetation usage**

In comparison to other genera, *Chiromantis* was observed utilising the highest number of plant families within NGR (Table 3.4). *Chiromantis xerampelina* showed a strong preference for the woody bark of trees and even using dead wood for call sites and building nests (Figure 3.7: H). Occasionally they were found using shrubs (Figure 3.7: I). The common denominator in all these plants used by *Chiromantis* was that they were either surrounded by water or their branches overhung water.

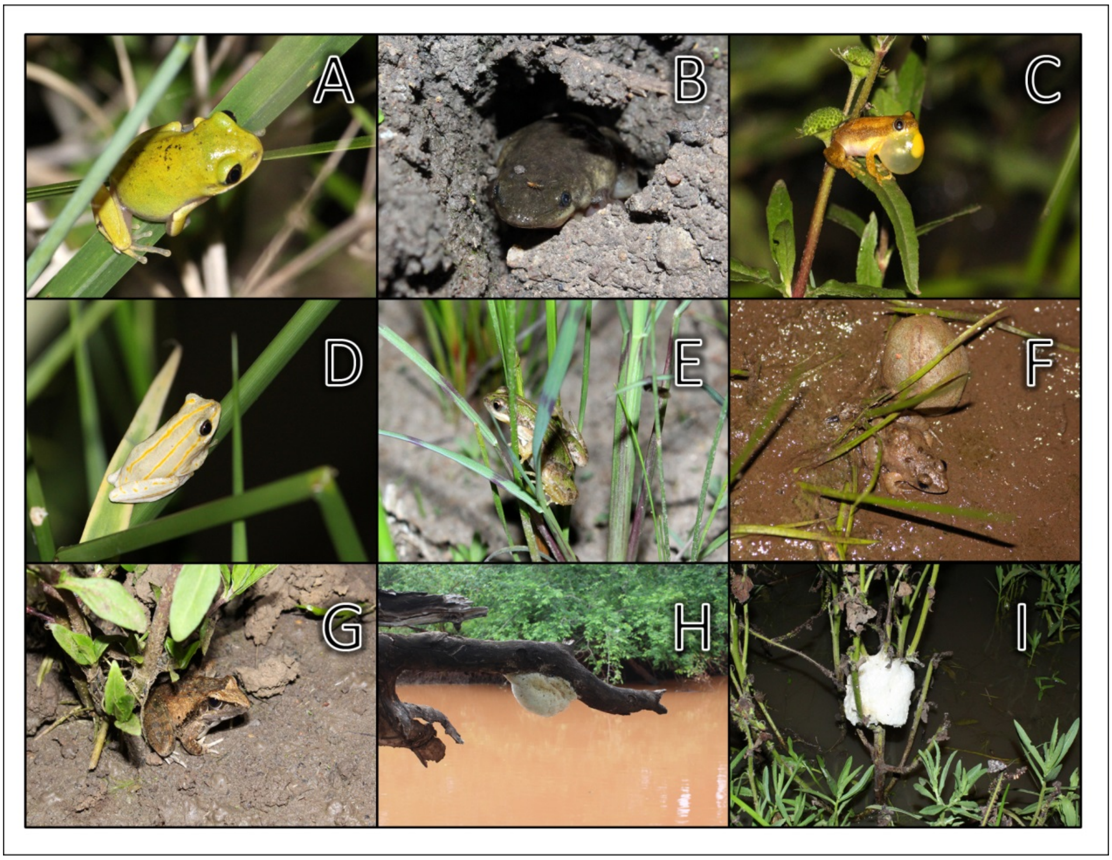


Figure 3.7: Plant usage by frogs at Ndumo Game Reserve.
A (*Leptopelis mossambicus*) Juvenile frog using plants for cover. **B** (*Hemisus marmoratus*) Some frogs showed no active plant usage. **C** (*Afrixalus delicatus*), **D** *(Hyperolius marmoratus)*, and **E** (*Cacosternum boettgeri*) Usage of plants as call sites. **F** (*Phrynobatrachus mababiensis*) and **G (***Ptychadena anchietae***)** Plant usage for presumably defensive behaviour. **H** and **I** (*Chiromantis xerampelina*) Using plants as nesting sites.

3.3.5 Inter-order and intra-order relationships

In addition to the survey providing a snapshot of anuran diversity at NGR, it also showed which other non-amphibian animals share their habitats and thus are also in competition for usage of resources. The taxa recorded sharing their habitat with NGR's frogs are testudines, siluriformes, perciformes, cyprinodontiformes, decapoda, crocodilia, and various freshwater invertebrates. There was no apparent trend in the grouping of different frog species found at the various sites. The observed territoriality relating to vegetation utilisation differed across frog species. *Leptopelis mossambicus* exhibited territoriality as no two calling males were found to share a tree and those calling from clumps of sedges were situated far from each other. Conversely, *C. xerampelina* displayed no territorial behaviour, as there would regularly be more than one male calling from the same tree and sometimes close to each other. No *Hyp. marmoratus* males were recorded sharing the culms or leaves they used as call sites. This territorial behaviour was also observed in *A. aureus* vegetation utilisation.

3.3.6 Exclusion of Zululand frog species from Ndumo Game Reserve

The 11 frog species distributed across the Zululand region but excluded from NGR fall into three families and eight genera (Table 3.5). Figure 3.8 depicts the distribution of these species in relation to the location of NGR. The distribution maps show a low likelihood of these 11 species occurring near the reserve (Figure 3.8). Netherlands (2014) surveyed a site located around 80 km from NGR and did not record any of the 11 species excluded from NGR.

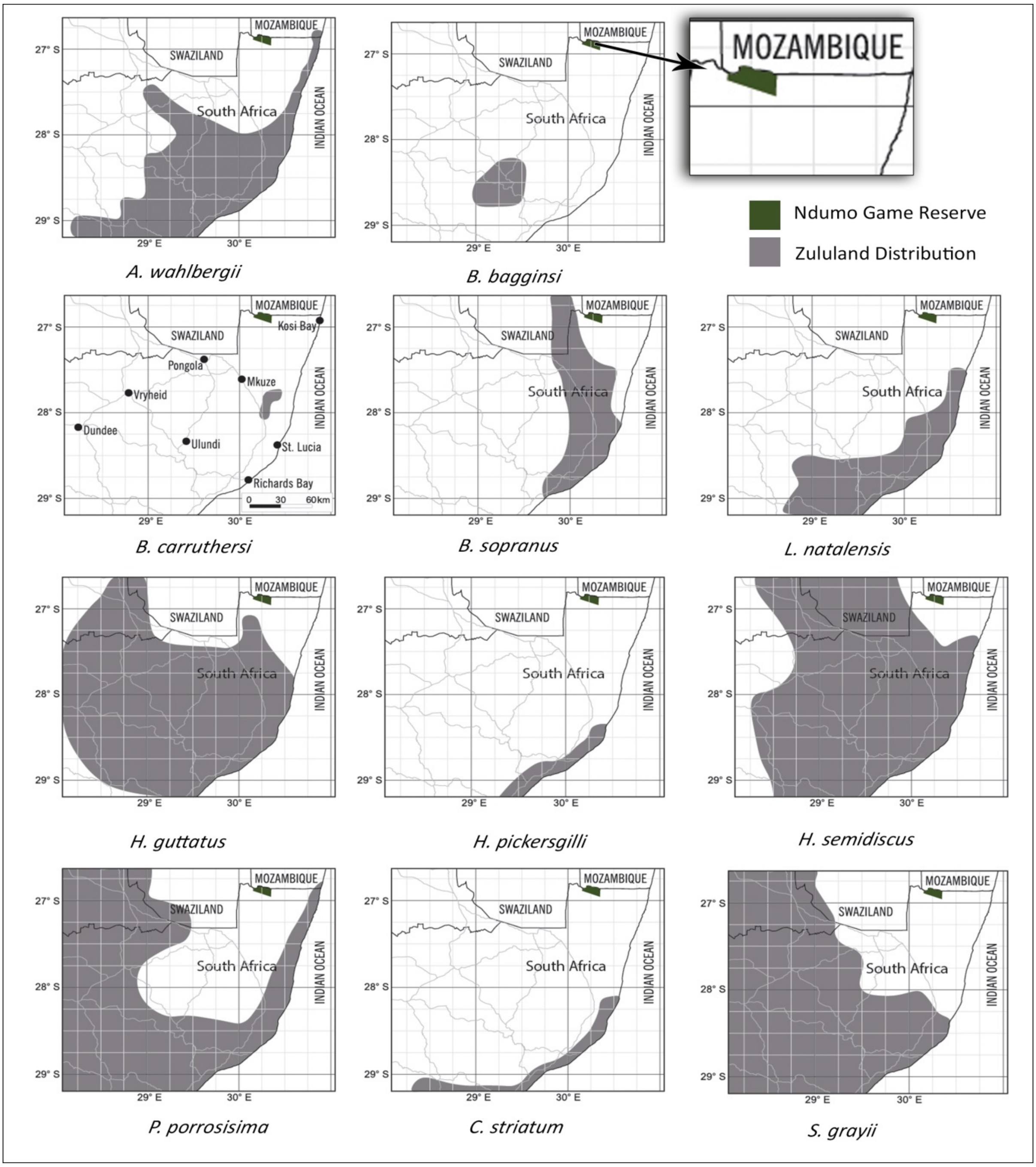


Figure 3.8: Distribution of frogs that occur in the Zululand region but are excluded from Ndumo Game Reserve. Distribution maps compiled using data from Minter et al (2004).

The preferred microhabitats for eight of the 11 excluded species are represented in NGR and no suitable microhabitats are available for the remaining three species (Table 3.5).

Table 3.5: Availability of preferred microhabitats inside Ndumo Game Reserve for species excluded from the reserve.

Excluded Species	Preferred microhabitats	Availability of preferred microhabitats inside the NGR (see Mucina and Rutherford 2006; SANBI 2012):
Arthroleptis wahlbergii	Forests, and thickets. (see Wager 1965; Lambiris 1988; Minter et al 2004)	Available
Leptopelis natalensis	Forests, Savanna biome, Riverine Thicket and Sand Forest. (see Wager 1965; Lambiris 1988; Minter et al 2004)	Available
Breviceps bagginsi	Grassy roadside verges near forestry plantations. (see Minter 2003; Minter et al 2004)	Not Available
Breviceps carruthersi	Makatani Clay Thicket and Western Maputaland Clay Bushveld vegetation types. (see Minter et al 2017)	Available
Breviceps sopranus	Forest and Savanna biomes. (see Minter 2003; Minter et al 2004)	Available
Hemisus guttatus	Found in Coastal Bushveld/Grassland, Mountain Grassland and Natal Central Bushveld. (see Wager 1965; Lambiris 1988; Minter et al 2004)	Not Available

Table 3.5 continued		
Hyperolius pickersgilli	Forest microhabitats. Swampy areas with dense sedge cover and stagnant water. (see Lambiris 1988; Minter et al 2004)	Available
Hyperolius semidiscus	Peripheral vegetation and emergent marginal vegetation of rivers and pans. (see Wager 1965; Lambiris 1988; Minter et al 2004)	Available
Ptychadena porosissima	Vleis, inundated grasslands and pans. (see Passmore 1978; Jacobsen 1989; Minter et al 2004)	Available
Cacosternum striatum	Grassland biome. (see Lambiris 1988; Minter et al 2004)	Not Available
Strongylopus grayii	Savanna, Thicket and Forest biomes. (see Wager 1965; Lambiris 1988; Minter et al 2004)	Available

3.3.7 Complete exclusion of frog species from habitats within Ndumo Game Reserve

The 42 species known to historically occur inside NGR and the recently described *B. passmorei* were not detected at nine of the 25 sites sampled during this study (Figure 3.9). At face value, these appear to be suitable microhabitats for frogs. They have grasses, sedges, reeds, and trees overhanging water. The terrestrial microhabitats have humid soil with a top layer of leaf litter. Water at Mjanshi Stream, Nyamithi Broken Bridge, Nyamithi Stream 1, Nyamithi Stream 2, and Nyamithi Stream 3 (Figure 3.9: C-G) was either stagnant or slow-flowing. Matendeni Stream 2 has relatively fast flowing water after rain but quickly degenerates to pools and puddles.

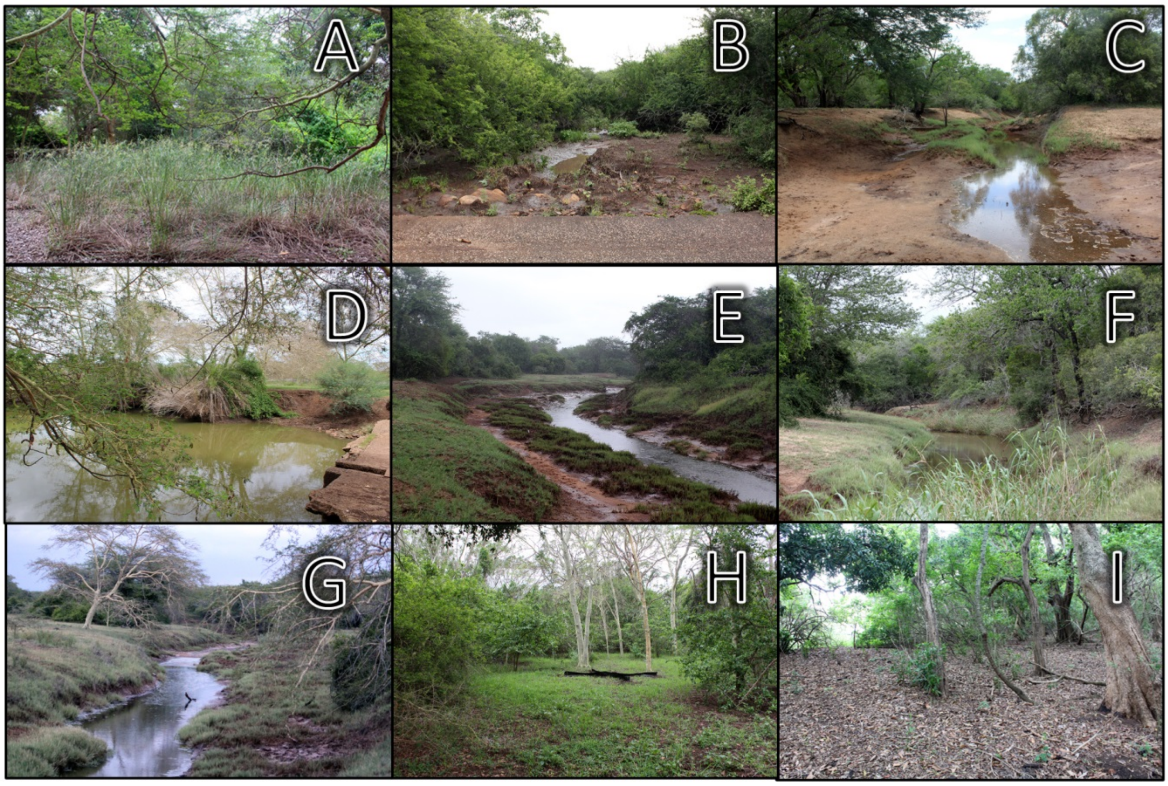


Figure 3.9: Habitats inside Ndumo Game Reserve where frogs were completely excluded. **A** - Banzi. **B** - Matendeni Stream 2. **C** - Mjanshi Stream. **D** - Nyamithi Broken Bridge. **E** - Nyamithi Stream 1. **F** - Nyamithi Stream 2. **G** - Nyamithi Stream 3. **H** - Terrestrial site 1. **I** - Terrestrial site 2.

The range of the water's pH and conductivity measurements at these sampling sites (barring the terrestrial sites) were lower in comparison to the 16 sites where frogs were not completely excluded (Table 3.2). Another common factor is the presence of *Oreochromis mossambicus*. This fish was actively recorded at Mjanshi Stream and Nyamithi streams 1–3 (Figure 3.9: C–G) using *Xenopus* traps in this study. Furthermore, this fish was noted to be present at Nyamithi Broken Bridge by a different study (see Welicky et al 2017). *Oreochromis mossambicus* was the only fish species recorded at five of the nine sites without frogs.

3.3.8 Partial exclusion of frog species from microhabitats within Ndumo Game Reserve

The 42 frog species historically occurring within NGR, are not excepted to occur at the same microhabitat or sampling site. Microhabitat requirements and seasonality of mating activity differ across species and this results in the partial exclusion of species from certain microhabitats (Table 3.6) or a difference in species composition. Investigating these partial exclusions helps further understand habitat utilisation and preference of various frog species. Factors causing this partial exclusion are not always obvious across all species, and this section only reports on those repeatedly noted in multiple sampling runs of the 16 NGR sites where frogs were not entirely excluded.

Table 3.6: Partial exclusion of frog species from microhabitats within Ndumo Game Reserve.

	Frog Species	**Number of sites excluded from out of a total 16**
	Arthroleptidae	
01	*Leptopelis mossambicus*	11
	Breviceptidae	
02	*Breviceps adspersus*	15
	Bufonidae	
03	*Schismaderma carens*	15
04	*Sclerophrys garmani*	13
05	*Sclerophrys gutturalis*	14
06	*Sclerophrys* pusilla	15
	Hemisotidae	
07	*Hemisus marmoratus*	10
	Hyperoliidae	
§08	*Afrixalus aureus*	12
09	*Afrixalus delicatus*	15
10	*Hyperolius marmoratus*	13
11	*Hyperolius pusillus*	15
12	*Phlyctimantis maculatus*	15
13	*Kassina senegalensis*	10
	Microhylidae	
14	*Phrynomantis bifasciatus*	10

Table 3.6 continued

	Phrynobatrachidae	
15	*Phrynobatrachus acridoides*	15
16	*Phrynobatrachus mababiensis*	7
17	*Phrynobatrachus natalensis*	13
	Ptychadenidae	
18	*Hildebrandtia ornata*	12
19	*Ptychadena anchietae*	5
20	*Ptychadena mossambica*	11
	Pipidae	
21	*Xenopus muelleri*	10
	Pyxicephalidae	
22	*Cacosternum boettgeri*	15
23	*Cacosternum nanum*	15
24	*Amietia delalandii*	15
25	*Tomopterna cryptotis*	14
26	*Tomopterna krugerensis*	10
	Rhacophoridae	
27	*Chiromantis xerampelina*	7

The highest occurrence of this partial exclusion occurred at microhabitats that had recently dried up. Thirty-eight of the 42 expected species were excluded from these dry sites as only three species (*H. ornata, P. anchietae* and *P. mababiensis*) were repeatedly recorded at dry sites sampled within NGR. *Afrixalus* spp. were excluded from sites without Clivias (amaryllidaceae), Daisies (asteraceae), Sedges (cyperaceae), or Grasses (poaceae) as emergent vegetation or vegetation overhanging water. *Hyperolius* spp. were excluded from sites without tall Grasses (poaceae) or Sedges (cyperaceae) as either emergent or overhanging vegetation. *Hyperolius pusillus* was recorded at the only wetland sampled during this study. *Chiromantis* sp. were absent from all dry sites, and sites without emergent vegetation or vegetation overhanging water. The species with the least recorded exclusion from sites was *P. anchietae* as it was detected at 11 of the 16 sites (Table 3.6).

3.3.9 Variation of amphibian species with habitat and vegetation

Detrended correspondence analysis results show the largest value in gradient length to be larger than 4.0 (Table 3.7). This result means that unimodal ordination methods are more appropriate to use (Lepš and Šmilauer 2003) for investigating amphibian species variation with microhabitat and vegetation type at NGR. Unimodal methods could however not be used as such methods cannot work with records in which no species are present (Lepš and Šmilauer 2003). The non-detection of species at some sites in this study meant unimodal methods were not appropriate despite what DCA indicated.

Table 3.7: Summary table obtained from running DCA on Canoco (Ter Braak and Šmilauer 2002).

	Axes				Total inertia
	1	2	3	4	
Eigenvalues	0.398	0.271	0.106	0.027	2.259
Lengths of gradient	5.267	3.899	1.994	1.855	
Species-environment correlations	0.153	0.624	0.278	0.517	
Cumulative percentage variance of species data	17.6	29.6	34.3	35.5	
Cumulative percentage variance of species-environment relation	2.8	36.3	0.0	0.0	
Sum of all eigenvalues: 2.259					
Sum of all canonical eigenvalues: 0.348					
None of the four eigenvalues reported above is canonical. The corresponding axes are not constrained by the environmental variables.					

The second axis is well correlated with microhabitat and vegetation (*r* = 0.624) in comparison with others. This suggests dominance of one gradient in this dataset (Table 3.7). The first gradient, microhabitat, which is also the longest accounts for 17.6% of total species variability. This first gradient and the second one cumulatively explain 29.6% of total species variability. The third and fourth gradients in this case are irrelevant as only two environmental variables (microhabitat and vegetation) were used for this analysis. This DCA suggests that microhabitat and vegetation type can cumulatively explain only 29.6% of amphibian species variability in NGR. Redundancy analysis (RDA) was employed to quantify the effects of microhabitat and vegetation on NGR's amphibian community.

Table 3.8: Summary table obtained from running RDA on Canoco (Ter Braak and Šmilauer 2002).

	Axes				Total variance
	1	2	3	4	
Eigenvalues	0.184	0.034	0.345	0.107	1.000
Species-environment correlations	0.628	0.623	0.0	0.0	
Cumulative percentage variance of species data	18.4	21.8	56.3	67.0	
Cumulative percentage variance of species-environment relation	84.4	100.0	0.0	0.0	
Sum of all eigenvalues: 1.000					
Sum of all canonical eigenvalues: 0.218					
The first two eigenvalues reported above are canonical, the other two are not since only two independent constraints can be formed from the environmental variables.					

The first axis explains 18.4% of the total variability in the species data (Table 3.8). The explanatory effect of microhabitat and vegetation is most significant in the first axis and is higher than the results obtained from DCA (Table 3.7).

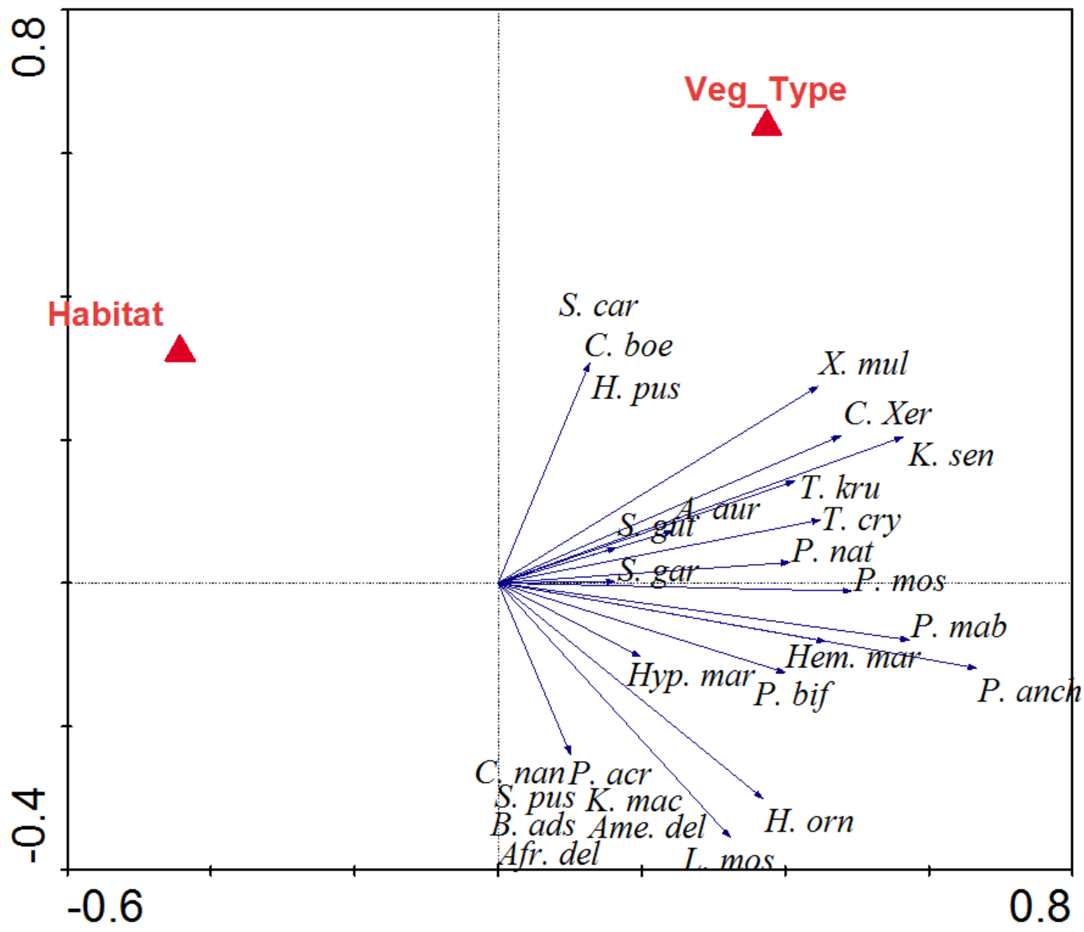


Figure 3.10: RDA species-environment (microhabitat and vegetation type) biplot diagram.

Distribution of species on the RDA species-environment (microhabitat and vegetation type) biplot shows a general variation in amphibian species composition at the sites sampled within NGR (Figure 3.10). The biplot shows vegetation type to have a greater effect on NGR's amphibian species composition than microhabitat type.

3.4 Discussion

Habitat usage is a vast and interesting natural science topic. The distribution of fauna and flora is often explained in terms of habitats used by these organisms. Animals are said to select habitats that maximize their individual lifetime fitness by influencing reproduction and survival (Fretwell and Lucas 1970). The global distribution of amphibians is tied to their preference of tropical and subtropical habitats (IUCN 2016). At a finer scale, amphibians show a strong preference for forest and freshwater habitats (see Roelants et al 2007; IUCN 2017a).

Within NGR, frogs exhibited a preference for endorheic microhabitats and the Makatini Clay Thicket vegetation type. This preferred microhabitat type is characterised by shallow and ephemeral water with banks that are inundated with grass, reed beds, and overhanging trees (du Preez and Carruthers 2009). The preferred vegetation type is characterised by melanic clay and clay loam soils (SANBI 2012). In comparison to the less preferred microhabitats, those with the highest anuran diversity had non-flowing water that dried up during some parts of the year. This contributes to reducing pressure on frogs and enabling increased diversity as many of their predators and competitors may fail to establish themselves in such conditions. The lowest numbers of species were recorded at temporary streams and lakes. This low occurrence is attributed to flowing and presence of predators (du Preez and Carruthers 2009).

The most frequently encountered species at the various sites sampled within NGR were *C. xerampelina*, *P. mababiensis*, and *P. anchietae*. These three species were also among the eight species found to have diurnal habitat utilisation in addition to their nocturnal habits. The other species exhibiting diurnal activity were *H. ornata*, *Hyp. marmoratus*, *P. mossambica*, *T. krugerensis*, *and X. muelleri*. Ambient temperatures of 45 °C were sometimes recorded during the day at NGR. Frogs use different thermoregulation techniques at ambient temperatures over 40 °C (du Preez and Carruthers 2009) and some of these techniques were observed at NGR. *Chiromantis xerampelina* thermoregulates through lightening its skin colour and dormancy, while *Hyp. marmoratus* used dormancy and the shade of shrub leaves (Figure 3.6: A–B). The other six frogs used the cool parts of sampling sites for thermoregulatory purposes (Figure 3.6: C–F).

The abovementioned occurrences of thermoregulation link to plant usage, as some of the species used plants to avoid high ambient temperatures (Figure 3.6: A; D). Plant utilisation is linked to species adaptations as species adapted for climbing were observed using more plants in comparison to species that are not adapted to climbing (Table 3.4). *Afrixalus* spp. and *Chiromantis* sp. showed a preference for vegetation that either overhung water or was emergent. The only difference was that *Afrixalus* spp. showed additional preference for plants with soft leaves and while *Chiromantis* sp. appeared to use plants indiscriminately (Table 3.4). *Afrixalus delicatus* prefer leaves that are easy to manipulate for oviposition (Backwell 2016).

The above text provides examples of how habitats enable presence of frogs. Habitats can also provide limiting factors for presence of species. The first step in investigating the exclusion of 11 Zululand frog species from NGR was to ascertain the availability of suitable microhabitats for the excluded frog species inside NGR. Of the 11 Zululand frog species excluded from NGR, only three had no suitable microhabitats inside the reserve (Table 3.5). Exclusion of the remaining eight species thus has to be explained by other means besides habitat availability. One of the possible reasons for exclusion, in this case, may be barriers to dispersal. The Maputo River or Great Usuthu River spans the northern side of NGR. Fast-flowing water and a higher number of predators in the water presents a barrier for any southward dispersal of *B. sopranus,* whose distribution range includes Mozambique (Minter et al 2004). West of the reserve there are the Lebombo mountains, Lowveld Riverine Forest, Subtropical Alluvial Vegetation and Southern Lebombo Bushveld vegetation types which are unsuitable habitats and potential dispersal barriers for *B. sopranus* and *P. porosissima* which have a range stretching west of the reserve into Swaziland.

Arthroleptis wahlbergii, *L. natalensis*, *B. sopranus, P. porosissima*, *C. striatum*, and *S. grayii*'s distribution range includes an area south of NGR (Minter et al 2004). The area between the end of their respective distribution ranges and the reserve is characterised by high human activity and land cover change as factors restricting these species to their range. Furthermore, the distribution of *L. natalensis* and *C. striatum* is localised to a relatively small area south of the reserve (Minter et al 2004). Zululand species with a distribution range including the area east of NGR (*A. wahlbergii*, *P. porosissima*, and *S. grayii*) have a vast area of Sandy Bushveld acting as a barrier between them and the reserve. The distance between NGR and the excluded frogs' distribution ranges also plays its role as a barrier to dispersal due to the unlikelihood of frogs surviving the long journey in order colonise the reserve.

The survival of most frog species is water-depended. Although some species have evolved ways to decrease this dependence on water, they still need some moisture to complete their life cycle (du Preez and Carruthers 2009). For example, *Breviceps* tadpole development takes place away from water but they still need moisture in their nests (Minter 1995). *Hildebrandtia ornata, P. anchietae* and *P. mababiensis* were recorded at sites after all water had evaporated and were also the only species recorded at small pools that occur immediately after rain. The detections of amphibian activity at dry sites, and the recorded movements of frog species in response to water availability (Table 3.3) suggests that some anurans employ strategies to be the first to colonise and utilise sites once their water has been replenished by rain. Furthermore, it suggests that frog species move away from or reduce activity at dry sites but do not completely abandon them.

Interspecific competition was expected to be a major factor contributing to the species composition of various microhabitats, but this did not appear to be the case in this study. Frog species with similar habits and microhabitat preferences were found co-existing at various microhabitats thus hinting at niche differentiation to allow for this co-existence. Niche differentiation in frogs is something that has been documented well in previous studies (see Heyer and Bellin 1973; Toft 1985). An investigation into amphibian species variation with microhabitat and vegetation type suggests that vegetation type has a greater effect on NGR frog species variation. However, this does not imply that the effect of microhabitat type on variance is not substantial. Microhabitat and vegetation type are interlinked. Soil is one of the defining characters for vegetation types as used by SANBI (2012) and it also a building block for habitats. The role played by soil in microhabitat and vegetation types makes it difficult to separate the individual effect of the two variables on species variance.

This study accounted for 27 of the 42 frog species whose historical distribution range includes NGR, leaving 15 species unaccounted for. A likely cause of this might be imperfect detection, which is inherent of all wildlife surveys (MacKenzie et al 2002). Non-detection or imperfect detection may be due to human error and can also be a result of factors beyond an observer's control such as seasonality of breeding activity, secretive habits of species and persistent drought conditions during the survey phase of this study. Employing several different sampling techniques in this study helped lessen the degree of non-detections, but it did not stamp them out altogether. Although the study surveyed 25 NGR sites, this was still not enough to cover the 10 117 ha nature reserve. Additionally, the survey only provides a snapshot of amphibian diversity and misses frog species that are active outside the survey period. Two of the 25 sites were subject to long-term monitoring through PAM to ascertain frog activity throughout the year. This monitoring was also not enough to cover the reserve's large area. Furthermore, these two sites are both endorheic microhabitats which belong to the Makatini Clay Thicket vegetation type. The two sites represent only one of the four microhabitat types and one of the four vegetation types recorded to be utilised by frog species inside NGR (Figure 3.4). Species that do not utilise endorheic microhabitats or Makatini Clay Thicket vegetation types may have possibly gone undetected. Persistent drought conditions provide a plausible explanation for non-detection in the current study. South Africa was experiencing one of its worst droughts when this study was carried out (Rautenbach 2016). However, the study by Netherlands (2014) was conducted before onset of the draught and still recorded 12 species less than the established baseline.

There is also the possibility of these 15 undetected species in this study having gone locally extinct from the reserve as a result of factors such as competitive exclusion, pressure from a rapidly increasing human population in the Zululand region, changing micro-climatic conditions within NGR, and climatic conditions that change too quickly for them to adapt as a result of accelerated climate change. This, however, can only be ascertained through long-term monitoring of more sites that are representative of different NGR microhabitats and a more exhaustive survey of the reserve. Such an undertaking would of course be a costly and time-consuming exercise.

3.5 Conclusion

This chapter demonstrates the importance of habitats for amphibian diversity. Habitats and the loss thereof has a bearing on biodiversity (Collins 2003). The mere existence of a habitat is not enough to maintain biodiversity as species have preference for certain microhabitats. Amphibian conservation efforts should thus not only focus on habitats but also include management plans for microhabitats. Habitat utilisation is a vital component of amphibian diversity that should ideally be monitored. Greater understanding of habitat utilisation at NGR in particular, and amphibian studies in general, can be achieved by using PAM at each microhabitat and vegetation type represented within a study area. A better understanding of how frogs interact with their habitat and react to changes within their habitat can help inform conservation efforts and plan for future changes that will be introduced through human land use and accelerated climate change. Such an understanding can help inform choices of habitats to protect and also assist with the restoration of degraded habitats.

Chapter 4: Community-Based Ecotourism in Ndumo Game Reserve: Making Biodiversity Data Relatable to Non-scientists

4.1 Introduction

Conservation areas are generally areas of high species richness in comparison to their surrounding landscapes. This richness usually correlates positively with dense human population which is consequently associated with increased threat to biodiversity (Balmford et al 2001). Threats related to dense human population are often cited among the many factors believed to be responsible for the rapid decline of amphibians. These threats include, inter alia, accelerated climate change, introduction of alien species, land-use change, and contaminants (Collins and Storfer 2003; Hof et al 2011). Complex interactions of multiple factors are put forward by some researchers as one of the most plausible explanations for amphibian declines (Blaustein and Kiesecker 2002; Collins and Storfer 2003; Beebee and Griffiths 2005). The rapid decline of amphibians has alarming implications for ecosystem health globally, and curbing this problem is one of the greatest conservation challenges of the current generation (Bishop et al 2012).

Nature reserves tend to exclude local people, and this is criticized as unsustainable due to pressures arising from those living along reserve boundaries (Bond and Frost 2005). Exclusion not only threatens the sustainability of reserves, it also hampers development as local communities are alienated from resources that could be used to promote economic and social change (Adams and Hulme 2001). The abovementioned characteristics of conservation areas are applicable to the Ndumo Game Reserve (NGR). It falls within the Maputaland-Pondoland-Albany Biodiversity Hotspot (Mittermeier et al 2011). There is a high diversity of amphibians and other taxa inside the reserve (see Pringle and Kyle 2002; Haddad 2003; Minter et al 2004; Haddad et al 2006.) The reserve's surroundings are characterised by high human activity such as agriculture and the built environment (Driver et al 2005; Jewitt et al 2015). Communities surrounding NGR are mostly rural and dependent on the reserve for resources (Meer and Schnurr 2013).

The reserve falls under the administration of Ezemvelo KZN Wildlife (Ezemvelo) and is part of the Lubombo Trans-Frontier Conservation and Resource Area (Patel 2006), which aims to formally connect NGR and Tembe Elephant Park with land in Swaziland and Mozambique (Meer and Schnurr 2013). This trans-frontier initiative has potential to promote ecological continuity and economic development. However, it has been criticized for issues such as seeking to remove communities who already have previously been translocated (Meer and Schnurr 2013), providing little scope for rural development (Dressler and Büscher 2008), and the likelihood that the initiative could contribute to tensions between local communities and NGR (Jones 2005).

The reserve has a turbulent past and many threats to the sustainability of NGR still persist today. Shortly after establishment of the reserve, local communities were forcibly removed from their land within its borders (Meer and Schnurr 2013). In the recent past local communities invaded the eastern section of the reserve (Carnie 2011). Meer and Schnurr (2013) noted that hostility from locals seemed to be increasing and has at times resulted in acts of violence and vandalism directed at the reserve, its visitors, and employees. In addition to the effects of exclusion, NGR's sustainability is further threatened by the communities' sentiments of land loss due to conservation initiatives, and a lack of transformation in the colonial institutions governing community-based natural resource management (Meer and Schnurr 2013).

Remedying the conflict between conservation and development goals is a matter of national and international importance. Aichi Biodiversity Targets (CBD 2011) recognise this disconnect between people and biodiversity as a contributor to biodiversity loss. The disconnect needs to be lessened in order to decrease the rate of biodiversity loss. Millennium Development Goal 15 is geared towards sustainable development of natural resources and curbing biodiversity loss (UN 2000). South Africa's 2015 National Biodiversity Strategy and Action Plan (NBSAP) speaks of biodiversity that provides South Africa's people with a rich heritage of nature-based cultural traditions and further reiterates that biodiversity is not as well understood as it should be (DEA 2015). One way to remedy conflict between conservation and development is to increase understanding of biodiversity and make it relevant to more people (Bickford et al 2012).

This chapter presents a novel, anthropocentric way of attempting to slow the rate of amphibian declines locally by decreasing the disconnect between people and biodiversity, specifically amphibian diversity. The chapter presents a contribution to striking a balance between conservation and development objectives at NGR through Community-Based Ecotourism (CBE). Citizen science is used to complement CBE.

4.1.1 Community-Based Ecotourism

Ecotourism in itself is a particularly appealing conservation and development tool as it has potential to provide local benefits and maintain ecological resource integrity through low-impact, non-consumptive use of natural resources (Stem et al 2003a). Community-based conservation initiatives emerged a few decades ago as one of the best tools for solving conservation and development issues (Meer and Schnurr 2013). Community-Based Ecotourism (CBE) seeks to place emphasis on the 'local benefits' part of ecotourism; it also aims to entrench a sense of environmental custodianship among the locals while also upholding the low-impact, non-consumptive use paradigm. This form of tourism is a particularly popular way of promoting biodiversity conservation in developing countries. The reasoning behind CBE is that local threats to biodiversity can be reduced by helping communities earn money from ecotourism, thus providing incentive for conservation and an alternative to destructive practices (Kiss 2004).

This does not mean, however, that CBE is a fool-proof way of achieving development and conservation objectives. The management paradigm at NGR includes elements of CBE, yet there is increasing hostility towards the reserve from local communities (Meer and Schnurr 2013). This hostility undermines development and conservation objectives by hampering progress of any development projects and increasing pressure on NGR's biodiversity. Some authors even believe that such hostility can be prompted by CBE initiatives (Klooster 2000) as communities perceive limited opportunities for meaningful participation in such enterprises (Brosius 2010). The hostility in NGR, which is sometimes in the form of violence and vandalism, is cited as an example of a community's desperate attempt to engage with conservation entities once all other avenues have been exhausted (Brosius 2006; Meer and Schnurr 2013). The ecotourism element of CBE also has its own pitfalls. Ecotourism success could spell failure in the long term as the success of such initiatives attracts an increasing number of tourists and multiplies negative environmental impacts such as habitat degradation and solid waste generation, thus threatening the very resources essential to ecotourism (Stem et al 2003a).

Most CBE projects have performed below expectations (Adams et al 2004; Kellert et al 2000; Barret et al 2001; Dressler et al 2010). This failure has been mainly attributed to improper implementation of projects and insufficient engagement (Songorwa 1999; Murphree 2002). Redford and Sanderson (2000) maintain that conservation and development objectives should be kept separate as CBE's mixed focus does justice to neither set of objectives. With its apparent drawbacks, there is still a need to successfully initiate CBE projects and involve local communities in conservation as a way of curbing the increasing biodiversity loss. Frogs are currently regarded as having limited usefulness in ecotourism or the upliftment of disadvantaged communities (Minter et al 2004). This is a perception that the study aims to change. The study area, NGR, is situated in a region of South Africa with the highest amphibian diversity. The region is also popular for its ecotourism attractions. Amphibians can potentially be introduced as another ecotourism attraction for the region. Empowering local communities to utilise frogs as an ecotourism attraction would then contribute to achieving both development and conservation objectives as is the goal of CBE.

4.1.2 Citizen science and Community-Based Ecotourism

Citizen science is another tool that can be used to include interested members of local communities in conservation, specifically in research aimed at conservation of biodiversity. Linking CBE with citizen science can increase the contribution to achieving development and conservation initiatives. Citizen science is an important tool for environmental research as it allows for dispersed data collection and involves non-scientists in places and at scales that were not previously possible (Dickinson et al 2010; Dickinson and Bonney 2012). The internet and Geographic Information Systems (GIS) enabled web applications allow for collection of large amounts of location-based ecological data which can be submitted to centralized databases electronically (Dickinson et al 2012). The wide availability of smartphones, potential to validate uncertain observations using digital photographs combined with development of infrastructure for creating simple online data-entry systems enables inexpensive initiation of projects with strict measures for data accuracy (Dickinson et al 2010).

Du Preez and Carruthers (2015) harnessed all the above technological capabilities into a software package for mobile devices known as the Frogs of Southern Africa (Frog App). The Frog App (Figure 4.1) additionally uses Global Positioning System (GPS) location combined with preloaded species distribution data to narrow the number of species that occur within the observer's current location. Following this, the observer can then answer four simple questions about the observed frog's morphology and the Frog App will display the most likely matches. In this way the Frog App assists with identification of frogs and makes identification in the field notably quicker for non-scientists and scientists alike. If there is significant uncertainty about the identification, then a photograph of the frog can be uploaded via the Frog App to a cloud database for review by a panel of experts who will then reply to the user with confirmation (Du Preez and Carruthers 2015).

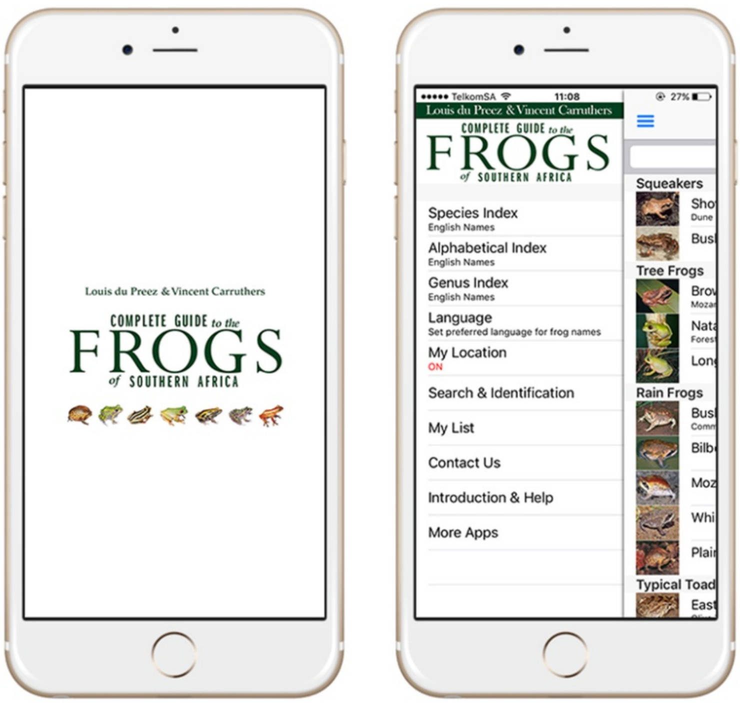


Figure 4.1: Graphic User Interface of the Frogs of Southern Africa mobile software application by Du Preez and Carruthers (2015).

Locations of frog sightings can be logged and uploaded to the FrogMAP database at the University of Cape Town's Animal Demography Unit, thus contributing regular data about the distribution of frog species. This FrogMAP is an ongoing citizen science initiative that seeks to map the distribution of African frogs and also determine conservation priorities. By assisting with identifications and users being able to upload photographs of their sightings to be reviewed by a panel of experts, the Frog App reduces the amount of observer bias usually associated with citizen science thus making non-scientist observations more reliable.

4.2 Materials and Methods

4.2.1 Site selection

The site selected for this study, NGR, presents an ideal case study for addressing conflict between development and conservation objectives. The reserve's high biodiversity is under pressure from increasing rural communities around the reserve as more people are looking to NGR for resources. Relationships between these communities and the reserve have historically been hostile and there is still some tension from time to time. The reserve has good ecotourism potential that can only be fully realised through better relationships between the reserve and surrounding communities. The reserve is particularly suitable for ecotourism focused on smaller animals due to it having less dangerous animals in comparison to other nature reserves in the area. It is especially popular among keen birders and lepidopterists. Low levels of economic development characterize communities around NGR and community members have expressed interest in being involved with the reserve.

4.2.2 Training field guides and developing frogging eco-tour methods

Nine local community members that demonstrated an interest in environmental matters, three NGR field guides, and two Ezemvelo employees were chosen as individuals to be trained as frogging guides and additionally collaborate in piloting CBE frogging safari methods. Community member's interest was gauged through interactions with them. Training was multifaceted as it incorporated an amphibian biodiversity workshop, the use of technology through the Frog App, and field visits to demonstrate some of the points discussed in the workshop. This amphibian diversity workshop took place on 28 November and 1 December 2016 at a lecture hall in Tembe Elephant Park. Lectures at the workshop focused on amphibian diversity and threats on global, regional and local scales. The list of presenters and their topics are listed below:

- FM Phaka: An Introduction to Amphibians.
- JE Reeder: DNA Identification of Amphibians
- WW Pretorius: Acoustic Identification of Amphibians
- EC Netherlands: Identification of Amphibians using Morphological Features

Each participant was given a copy of A Complete Guide to the Frogs of Southern Africa (Du Preez and Carruthers 2009), to use as reference for the part of the lecture dealing with regional and local amphibian diversity (Figure 4.2).

Figure 4.2: Zululand community members using a book by Du Preez and Carruthers (2009) as reference material during an amphibian diversity workshop.

The lecture was followed by a practical class on frog identification using specimens caught in the vicinity of the workshop venue. The frogs were kept in plastic containers to decrease handling stress and released at original site of capture after the practical demonstrations. Identifications were based on morphological features using the identification key in Du Preez and Carruthers (2009). The morphological features in question included, inter alia, colour, pupil orientation, limb length, presence of webbing and claws on limbs, and presence of bulbs on fingers. Participants were taught during field visits how to identify, catch, and handle frogs. Only the three NGR field guides were taken on field visits due to the reserve’s regulations. The guides were given access to a mobile tablet device preloaded with the Frog App to use on the field visit and subsequent frogging eco-tours (Figure 4.3). Frog identification relied firstly on advertisement calls upon arrival at sites identified during the amphibian survey part of this study. The Frog App assisted with identifying frogs by their advertisement calls. The identity of the calling species could be confirmed by playing back the call on the mobile application.

Figure 4.3: Demonstrating use of the Frog App (Du Preez and Carruthers 2015) to Ndumo Game Reserve's field guides. (© Edward Netherlands)

Depending on the sensitivity and safety of a site, the guides could then proceed to catch frogs and work on identifying them. Frogs were caught by hand and transferred to transparent plastic containers to reduce handling stress during identification. The Frog App was used to assist with identification of frogs using morphological features in the field.

In order to change the perception of frogs not being useful in ecotourism and community upliftment, information about them has to be presented in a manner suited for tourism and also be translated into more tangible worth for people. The survey and monitoring data collected during the sampling phase of the study was packaged as tourist information that the NGR field guides could use whenever they have guests. The guides could thereby increase their arsenal of attractions on offer, and guests would walk away with a more diversified experience of NGR. Species occurrence data was saved on the Frog App to allow for easy updating and ease of reference while with guests. Additionally, the Frog App has information about the biology of the species whose location has been logged.

Any information that could not be saved or was not already available on the Frog App was presented at the amphibian diversity workshop. This workshop also served as a consultation session with locals and NGR guides in order to understand their curiosity about frogs, how they perceive frogs, and how their culture relates to frogs. The sessions were also used to learn about misconceptions that communities surrounding the NGR have about frogs. Extraction of required data during these consultations was done through initiation of frog-related conversations with local community members. Through these conversations the locals shared their frog-related curiosities, perceptions and cultural beliefs.

4.2.3 Finding out about interest in frogs as a tourist attraction from Ndumo Game Reserve's field guides

Besides, understanding cultural issues regarding frogs, the workshop also served to survey the level of interest in frogs as tourist attractions at the NGR. The three NGR guides were surveyed on the following points in order to ascertain the level of interest in frogs as tourist attractions (Appendix E):

1. How often do guests ask about frogs or request to see frogs when booking a safari?
2. How often are guests intrigued by frog advertisement calls while on safari?
3. How often do guests ask frog related questions while on safari?
4. Guides' willingness to learn about frogs and include them in guiding repertoire.
5. Guides level of knowledge about frogs.

The guides were asked to rate their response on a scale of 1–5. A response of 1 denoted a negative answer to a question or undesirable response for prospects of having frogs as tourist attractions at NGR. A 3 was a neutral or indifferent response while a 5 indicated the most desirable response for prospective frogging eco-tours. This survey of the interest of frogs as tourist attractions served to test whether there is demand for frogging eco-tours from NGR guests and also judge the willingness of the field guides to meet such a demand if it does exist.

4.2.4 Developing a bilingual field guide to the frogs of Zululand

As a means to further derive socio-economic benefits from amphibian biodiversity at the NGR and the Zululand region at large, the handbook “A Bilingual Field Guide to the Frogs of Zululand” (Phaka et al 2017) was compiled (Appendix C). Lessons learned from the consultation sessions formed a point of departure for the book. The community’s curiosity, perceptions, and cultural views relating to frogs informed how this book was written. This guide was compiled for the region of Zululand as opposed to only NGR so it would appeal to a wider audience as well as cover each workshop participant’s respective area of residence. The workshop participants were from five different parts of Zululand. Thus, a significant amount of the region’s interests, perceptions, and cultural views relating to frogs are explained in the book.

The introductory section of the book presents what the community members expressed interest in learning about frogs and applies scientific contexts to how they perceive and relate to frogs. In the same section misconceptions about frogs are dispelled and interesting but little-known information about frogs is disseminated. This is done in a style of writing that is geared for a popular audience and has minimal scientific jargon. The book is written in IsiZulu and English as these are the most widely used languages in the region (Stats SA 2014). Information in this book is presented in a manner that is conversational, uncondescending, and also respects aspects of the Zululand community’s culture.

The species description pages of this book illustrate types of frogs found in Zululand. These species description pages follow the process from first seeing a frog to finally reaching a positive identification. Generally, when you encounter a frog you first notice its size, colour and the structure of the body. Upon close inspection, you start to notice the finer details of its morphology, including the shape of the head, features of the forearms and hind legs, visibility of the tympanum, and feel of the skin on the back and the underside. As you improve in your ability to distinguish morphological features of frogs you also become better at determining sexual dimorphism. You also learn how to differentiate species using key identification points.

The Zululand region's amphibian diversity baseline was found to be 52 species (see Wager 1965; Lambiris 1988; Minter et al 2004). However, the number of species depicted in the Zululand guide is increased to 58. Two new Zululand species, *Breviceps carruthersi* and *Breviceps passmorei*, were discovered during this study (Minter et al 2017) and these increased the number to 54 species. Four other species' distributions are close to the boundaries of this study's delineation of Zululand. These four species (*Breviceps bagginsi, Hadromophryne natalensis, Natalobatrachus bonebergi,* and *Tomopterna tandyi*) were thus likely to be encountered by Zululand communities whose settlements stretched between Zululand boundaries and the species' distribution ranges. Based on this likelihood, these species were also added thus increasing the number of species described in the book to 58.

A Bilingual Field Guide to the Frogs of Zululand (Phaka et al 2017) has four authors who are listed below along with their roles and contribution to the book.

- Fortunate M. Phaka – Lead author and main researcher.
- Edward C. Netherlands – Contributing author and research Assistant Supervisor.
- Donnavan J.D. Kruger – Contributing author and research Co-supervisor.
- Louis H. du Preez – Contributing author and research Supervisor.

4.2.5 Practical training of field guides

A final aspect of training the frogging guides is to test their readiness to take visitors on frogging eco-tours. Through frogging eco-tour dry-runs the field guides will be evaluated, training methods refined, and guides re-trained in aspects they did not grasp before. The first of the dry-runs took place on 8 December 2016 when one of the NGR field guides (Bongani Mkhize) took two guests (Koos and Karin Janse van Vuuren) on a frogging eco-tour. These evaluations will continue past completion of this study. Evaluated aspects in these frogging eco-tour practice sessions are their presentation of information about frogs to their guests, searching and handling of frogs, and assessment of how they deal with safety and sensitivity of the frog habitats they visit.

4.3 Results

4.3.1 Challenges

Introducing CBE to NGR and surrounding communities has proved problematic for various reasons. For community members to carry out frogging eco-tours inside the reserve they have to be qualified field guides. Unfortunately, field guide training and associated costs fall beyond the scope of this study. Opportunities for meaningful participation in CBE initiatives are often perceived by community members to be limited to just a few community members (Brosius 2010). Presenting amphibian-inspired crafts as viable curios in the market surrounding the reserve would circumvent this challenge as more community members could derive monetary benefit from the local amphibian diversity. However, the curios market around NGR is almost non-existent as most of the locals opt for selling firewood by the roadside. The challenges to introducing CBE's monetary benefit aspect to the Zululand community could not be overcome. The study could thus only focus on the educational outreach and conservation awareness elements of CBE, and the training of existing NGR field guides to carry out frogging eco-tours. The results of this reduced-focus CBE are presented below.

4.3.2 Translating monitoring and survey data to tourism information

The species occurrence data obtained from survey and monitoring of amphibian diversity at NGR was logged on the Frog App for the field guides to use. This occurrence data was saved according to the sites where each species was detected (Figure 4.4). Grouping this occurrence data according to site was aimed at helping NGR field guides know which species to expect at a particular site and which sites are frog diversity hotspots within the reserve.

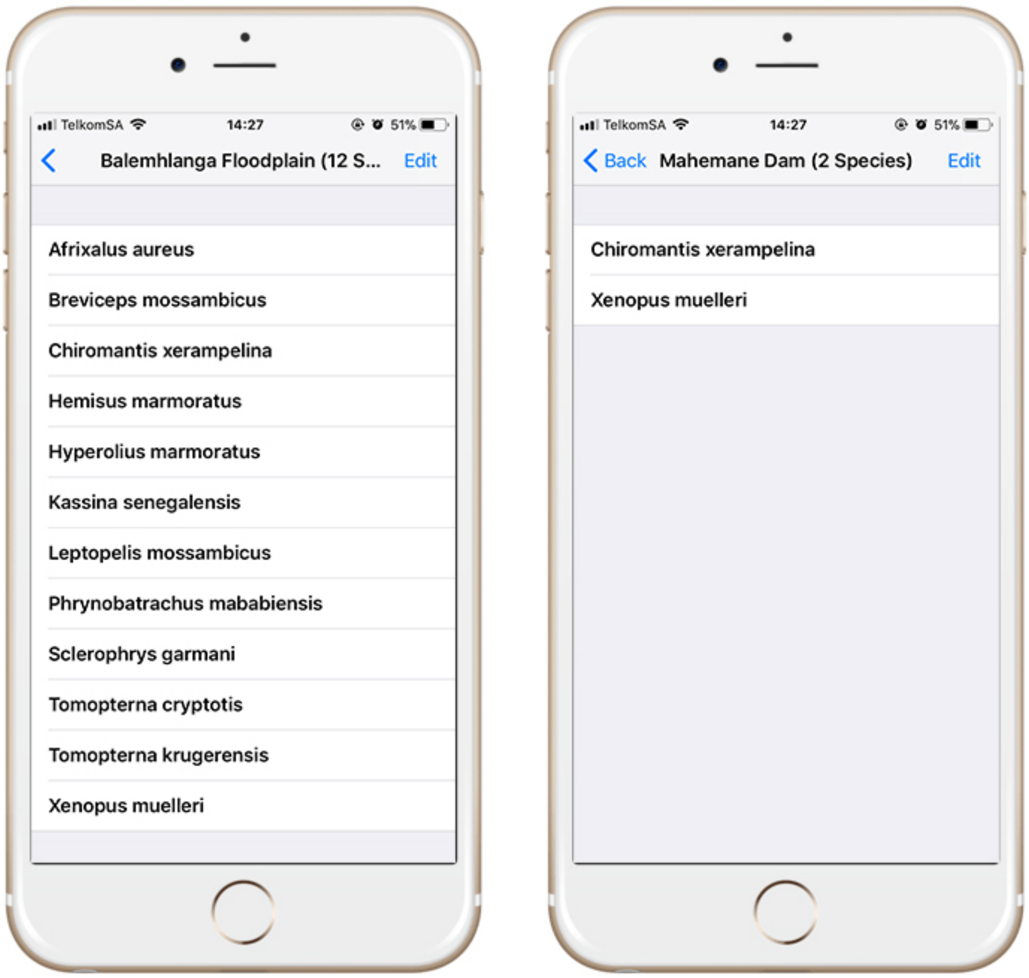
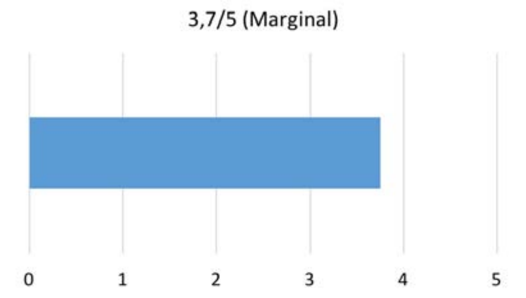
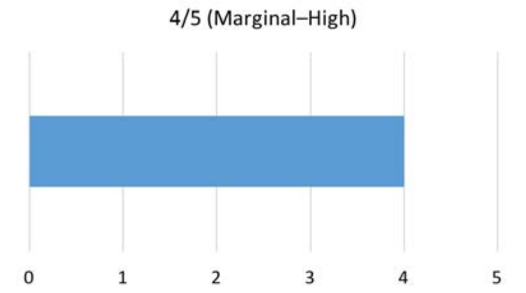
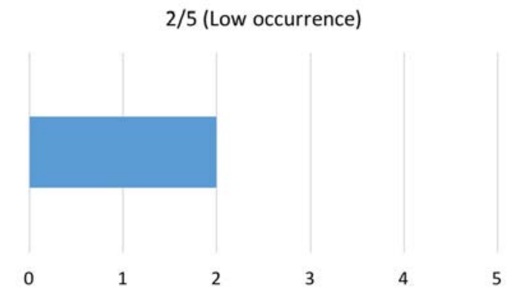
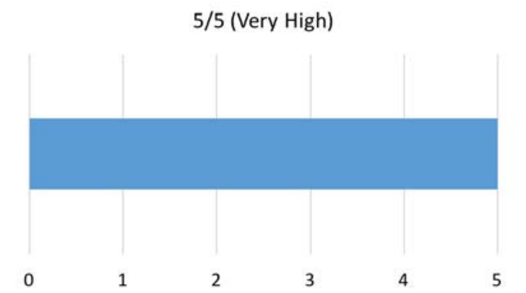
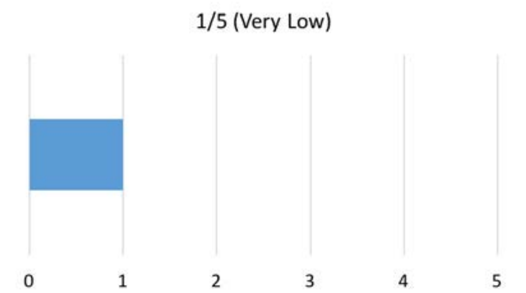


Figure 4.4: An example of species occurrence data per site saved on the Frog App (Du Preez and Carruthers 2015) for field guides to use.

4.3.3 Interest in frogs as a tourist attraction

The survey results suggest that NGR guests are interested in frogs as an additional tourist attraction at the reserve. Furthermore, NGR field guides show an interest in frogs as a tourist attraction, but their level of amphibian knowledge was found to be low (Table 4.1).

Table 4.1: Results from surveying interest in frogs as a tourist attraction in Ndumo Game Reserve

	Survey Question	Answer
1.	How often do guests ask about frogs or request to see frogs when booking a safari?	
2.	How often are guests intrigued by frog advertisements calls while on safari?	
3.	How often do guests ask frog related questions while on safari?	
4.	Guides' willingness to learn about frogs and include them in guiding repertoire.	
5.	Guides level of knowledge about frogs.	

4.3.4 A Bilingual Field Guide to the Frogs of Zululand

The handbook, "A Bilingual Field Guide to the Frogs of Zululand" (Phaka et al 2017) was developed as part of the present study. It represents South Africa's first indigenous language frog field guide, being written in both Zulu and English (Appendix C; Figure 4.5). Readers can switch to their desired language by flipping the book. This book was published by the South African Biodiversity Institute (SANBI) as part of their peer-reviewed *Suricata* journal series.

Figure 4.5: Front cover of 'A Bilingual Field Guide to the Frogs of Zululand' (Phaka et al 2017).

An electronic version of this book is to be made available on SANBI's Biodiversity Advisor online platform as an addition to the *Suricata* section of the literature tab; (http://biodiversityadvisor.sanbi.org/literature/). The electronic version will be similar to the hard copy version but will include a functionality allowing playback of advertisement calls for all the species featured in the book.

New isiZulu frog names were formulated for the book as they did not exist for many of the Zululand species. The participants of the amphibian diversity workshop provided clarity on existing names to help modify them and formulate new ones. Bongani Mkhize, one of the NGR field guides, assisted with formulating 30 new isiZulu frog names and modifying 28 existing names from a book by Tarrant (2015). The Zululand community was found to have isiZulu common names for groups of species as opposed to having one common name per species. Nomenclature of existing isiZulu common names is roughly based on similarities in habit:

- 'Umgqagqa' generally refers to Reed Frogs or Leaf-folding frogs (Hyperoliidae);
- **'**Isinana**'** generally refers to fossorial frogs (Breviceptidae and Hemisotidae);
- **'**Idwi**'** generally refers to aquatic frogs (Pipidae);
- **'**Ixoxo**'** generally refers to species with granular or warty skin (Bufonidae); and
- **'**Iselesele**',** which is sometimes shortened to 'isele', generally refers to the smoother skinned species. This also includes other species not covered by the above names.

Words describing individual species were added to these existing 'group' names to extend them and assign a unique name to each Zululand species. These names were extended in such a manner that their isiZulu meaning would be similar to their English counterparts for each species.

4.3.5 Ndumo Game Reserve frogging eco-tours as a pilot for larger scale frogging eco-tours

One frogging safari practice session took place on 08 November 2016. Two guests opted for a frogging eco-tour as an additional extra to their birding safari. All aspects of the safari were good except the presentation of the information about frogs. The field guides were still uncertain about some facts as they still required time to learn about the biology and interesting facts of the 43 species they could possibly encounter at NGR. More practice sessions could not be held as drought conditions decreased amphibian activity and the number of guests visiting NGR. Frogging eco-tours are now advertised at the NGR's main entrance (Figure 4.6).

Figure 4.6: A board advertising frogs as a tourist attraction at the main entrance of Ndumo Game Reserve. (© Edward Netherlands)

The eco-tours are offered as a free optional extra on night drives during evaluation and re-training of field guides. Once the guides are deemed ready, this optional extra will be available to be charged to participating NGR guests. While on these eco-tours, guests and field guides listen for advertisement calls which they use to locate frog microhabitats while inside the safari vehicle. Upon arrival at each microhabitat the field guide climbs out of the vehicle to assess the microhabitat's sensitivity to change and whether it will be safe for guests to be out of the vehicle. If microhabitats are sensitive only the field guide will step out of the vehicle to actively search for frogs and bring them back to the vehicle to identify them with guests. Field guides can invite guests to step out the vehicle and participate in active searches at microhabitats that are deemed safe for them and also able to withstand trampling. After identification of captured specimens, they are released at their original place of capture before the field guide proceeds to talk about the frog's biology and conservation status. The protocol for handling frogs is the same as the one used in this current study (and discussed above at section 2.2.5). Since drought conditions limited progress in piloting frogging eco-tours at NGR, this aspect of the study will continue past submission of this thesis.

4.4 Discussion

The failure to fully implement CBE as originally envisioned in this research project shows that flexibility from a conservation area's management is vital to CBE success. Flexibility from management would enable community members to take part in field visits and obtain more practical experience in identification and handling of frogs. This type of management would also foster increased engagement with the community. Insufficient community engagement can impede the success of CBE initiatives (Songorwa 1999). Another key part of CBE is curios markets that will help increase the number of people benefiting from amphibian diversity and lessen feelings of being excluded from CBE initiatives as mentioned by Brosius (2010).

Implementation of this CBE initiative has also highlighted the importance of nature reserves in amphibian conservation. Reserves act as a conduit of biodiversity data through tourism. Sensitising guests to the conservation risk of the biodiversity they have come to view is relatively easy as they have already attached sentimental value to wildlife. Conservation management buy-in is vital to maximising conservation value of this conduit. The NGR's management, Ezemvelo, has afforded the amphibian conservation agenda a chance at advancement by allowing the piloting of frogging eco-tours and being open to aspects of CBE.

The CBE aspects that went ahead successfully managed to pioneer novel ways of simultaneously advancing conservation and development objectives. Designing a frog field guide around people is a unique way of achieving these objectives. A sense of ownership towards the book was instilled in the participants from the onset with consultation sessions aimed at learning from them. The book captures the lessons learned in the sessions. Furthermore, presenting the book in participants' home language is something that will be appreciated as it is published during a time when a lot of South Africans are calling for greater use of indigenous languages. Through meaningful attachment to this book, Zululand community members are unwittingly being sensitized to amphibian biodiversity matters.

The citizen science element introduced by the Frog App also contributes to amphibian conservation through monitoring. The Frog App at least in a small way promotes Information and Communications Technology (ICT) in a part of South Africa where ICT development is low. It also assists with identification using morphological features and advertisement calls in the field and significantly reduces the chances of misidentification. This feature of the Frog App adds validity to data collected using the mobile application. Additionally, the Frog App makes teaching and frogging eco-tours interactive. Anyone can participate in identifying a frog, and for frogs that were 'only heard but never seen' the Frog App provides a reference photo along with information on its biology. Acquiring the Frog App or a device to operate it on is however costly. Intervention may be required from Ezemvelo in the form of making devices loaded with the application readily available to staff members.

The survey into the interest in frogs as a tourism drawcard reveals that this interest exists in both guests and field guides alike. Frogs catch the attention of guests while on safari, but they soon lose interest because there is little information about them from their guides and they are also not promoted as attractions. These results are to be interpreted with caution due to the small survey sample size as a result of the limited number of field guides available at NGR. Guests could not be surveyed as there was a low number of guests at NGR due to severe drought, and out of respect for the privacy of the few available guests. Furthermore, it is worth noting that NGR typically attracts guests that are interested in ecotourism and tourist attractions that are not the 'Big 5'. Thus, the interest in frogging eco-tours may not be as high at Big 5 reserves.

Frogging eco-tours stand a greater chance of being mainstream if they are optional extras to existing safaris and not a standalone safari package. Big 5 and birding safaris are well-established and difficult to compete with. Packaging frogging eco-tours as optional extras would complement these established tourist attractions as opposed to attempting to compete for guests. Frogs are a non-perennial attraction while Big 5 and birding safaris are year-round drawcards. Thus, attempting to have frogging eco-tours as a standalone attraction would make them a seasonal attraction that risks losing guests that are forced to find other attractions during the off-season. Frogging eco-tours as standalone attractions could also degrade sensitive frog habitats. Ecotourism success can create problems as an increase in tourist numbers multiplies negative environmental impacts (Stem et al 2003a). If the frogging eco-tours are standalone, then the number of guests would have to be increased in order to make frogging eco-tours a viable, profitable attraction. An increase in guests translates to a greater chance of trampling habitats and disturbing breeding activity.

Presenting frogging eco-tours as an additional extra to existing safaris offers more benefit for both humans and amphibians. Guests on safari would get a more diversified safari experience, damage to frog habitats would be minimised and people would be sensitized to their importance. Dry-runs of the eco-tours will continue past this current study so field guides can be evaluated and retrained. Frogging eco-tours at the NGR will be monitored to ascertain how they fair as an additional tourist attraction. The frequency of bookings will be monitored to investigate popularity of these safaris. Feedback will be sought from guests to find out more about their frogging safari experience, investigate how well the guides fair in the field and also gain pointers on how to improve training methods and the frogging eco-tours themselves. The lessons learned from this monitoring will contribute to improving NGR frogging eco-tours and developing methods to introduce frogging eco-tours on a larger scale.

4.5 Conclusion

The amphibian diversity workshop, the effort to make frogs a regular tourism feature and the frogging guide that specifically caters for the Zululand context are all means of mainstreaming biodiversity issues across South Africa's non-scientific community. This has the potential to contribute to relieving pressure on biodiversity while deriving benefits for people from biodiversity. Lessening the disconnect with biodiversity supports various international and national conservation strategies which include, inter alia, Aichi Biodiversity Target's Strategic Goal A and Goal B (CBD 2011), Millennium Development Goal 15 (UN 2000), South Africa's 2015 National Biodiversity Strategy and Action Plan (DEA 2015), and the Biodiversity Management Plan for Pickersgill's Reed Frog (Hyperolius Pickersgilli) (DEA 2017).

Findings of this study are contrary to a long-held belief that non-scientists or local communities are ignorant to or uninterested in biodiversity issues. Other studies have arrived at similar conclusions, with an additional revelation that locals are generally not opposed to nearby reserves per se, but rather are opposed to their management structures (see Harcourt et al 1986; Infield 1988; Newmark et al 1993). Locals of the Zululand community that joined the amphibian diversity workshop exhibited an interest in frog biodiversity matters and also showed interest in learning about other wildlife.

Frogging eco-tours are unlikely to attract interest as a standalone tourist attraction due to competition from the well-established Big 5 and birding safaris, and misgivings people have about frogs. Frogging eco-tours are better packaged as optional extras from both conservation and tourism perspectives. From a tourism perspective this would mean a more diverse experience. For conservation purposes, damage to frog habitats would be minimised while awareness of their importance is increased. Piloting methods of introducing frogging eco-tours on a larger scale was delayed by severe drought. Piloting will continue past submission of this dissertation and the results obtained will be used to develop methods of introducing frogging eco-tours beyond NGR's borders. When introducing frogging to other reserves their contexts will be considered as not all reserves cater for ecotourism.

Chapter 5: Summative Discussion

5.1 General Discussion

Ndumo Game Reserve (NGR) is located in a region that is internationally recognised as a biodiversity hotspot (Mittermeier et al 2011). The reserve itself is a biodiversity hotspot within South Africa (see K.L. Tinley and W.T. van Riet, unpubl. data 1981; Pringle and Kyle 2002; Haddad 2003; Haddad et al 2006) and is in a part of the country with the highest amphibian diversity (Minter et al 2004; Du Preez and Carruthers 2009). The province within which the reserve is located, KwaZulu-Natal (KZN), has South Africa's second highest population density (see Stats SA 2014; Stats SA 2017), and one of the highest rates of natural habitat loss (Jewitt et al 2015). A causal relationship between high human population and natural habitat results in threat to biodiversity. This threat is in turn a threat to ecosystems and ecosystem services upon which humans are dependent. This causal relationship presents a conflict between conservation and development which needs to be resolved if national and international strategic conservation goals are to be achieved (see UN 2000; CBD 2011; DEA 2015, DEA 2017).

This study is a recognition of the urgency needed in solving this conflict and the pivotal role science has to play in any formulated solution. Through monitoring, surveying and collection of historical data the study compares current amphibian diversity with what was previously known to occur at NGR. The results reported on in Chapter 2 indicate the number of detected species in NGR is lower than the baseline number established from historical records. The 2014 study by Netherlands also recorded lower diversity in comparison to historical records. The amphibian diversity recorded in this study was even lower than what was recorded by Netherlands (2014). This trend could possibly mean a local extinction of certain frog species from NGR. However, the reduced species numbers could be a result of imperfect detection during sampling, seasonal behaviour, or persistent drought conditions reducing activity of certain species. Preliminary investigations into the relationship between amphibian diversity at NGR, human population increase and natural habitat loss in KZN hint at the possibility of local extinctions. The results of this investigation suggest that amphibian diversity at NGR may be decreasing as human population increases and natural habitat decreases.

These preliminary results are in line with global amphibian declines (see Wake 1991; Stuart et al 2004; Bishop et al 2012). Chapter 2's results highlight an urgency for ongoing amphibian diversity monitoring in order to gain solid evidence of suspected declines. Further urgency is required in the conservation of amphibian diversity in order to protect available diversity and curb any ongoing declines. Chapter 3 aimed to investigate how the amphibian diversity studied in Chapter 2 utilises habitats within NGR. The results showed a preference for endorheic and palustrine habitats. The most utilised vegetation type was found to be Makatini Clay Thicket. Nocturnal activity was recorded in all of the 27 species detected in this study and eight of the 27 species were additionally found to be active during the day. At least 11 plant families were found to be utilised by frogs inside NGR. The relationship of sampling covariates with amphibian species occurrence were investigated in order to explain presence or absence of species from certain habitats. A combination of covariates may result in the exclusion of species from certain habitats but what emerged as the strongest determinants of amphibian exclusion are dispersal barriers, and availability of suitable habitats.

The outcomes of Chapter 3 provide evidence that amphibian conservation efforts should not only focus on preservation of habitats but also place emphasis on protection of microhabitat integrity. A lot of the suspected causes for amphibian declines are linked to human activities. To lessen these threats would need a lessening of the disconnect between humans, specifically non-scientists, and biodiversity. Chapter 4 aimed to achieve this through Community-Based Ecotourism (CBE) which is a tool believed to be best suited for simultaneously fulfilling conservation and development objectives (Meer and Schnurr 2013). The aim of Chapter 4 was partially achieved as only some CBE aspects were successfully implemented. Zululand community members could not be involved in frogging eco-tours due to NGR's regulations which imposed challenges the study was under-resourced to overcome. The lack of a curios market around NGR meant that the study could not extend CBE benefits to more Zululand locals. A successfully carried out amphibian diversity workshop revealed that there is an interest in having frogs as tourist attractions at NGR. Plans to introduce frogging eco-tours to NGR went ahead albeit with participants limited to the reserve's field guides. Persistent drought conditions slowed progress with introduction of frogging eco-tours, and as a result this section of the study will continue past submission of this thesis.

5.2 Future Research

This entire study served to pilot means of mainstreaming amphibian diversity while contributing to survey and monitoring of South Africa's amphibian diversity. Lessons learned will inform larger scale studies aimed at promoting amphibian conservation while contributing to survey and monitoring of frogs. The preliminary investigation pointing to possible decline of amphibian diversity within NGR highlighted a need for ongoing monitoring of amphibian population dynamics. Amphibian habitat utilisation also requires monitoring to better understand mitigation required to counteract the negative effects of habitat degradation. The possibility of co-occurrence of *B. adspersus* and *B. passmorei* requires an in-depth investigation. The recently described *B. passmorei* is cryptic (Minter et al 2017) and what was thought to be *B. adspersus* in this and previous studies could be *B. passmorei*.

Learnings from the present study gathered through introducing frogging eco-tours to NGR will inform efforts to introduce these eco-tours on a larger scale both in NGR and across South Africa. A new study will carry forward work started in this current study. This will include application of lessons learned in the amphibian diversity workshop and through drafting of the frog handbook. These lessons will assist in improving methods of communicating the importance of amphibian biodiversity and how to better use the Frog App as an Information and Communications Technology (ICT) and citizen science tool.

In future studies efforts to help communities derive non-consumptive monetary benefit from amphibian biodiversity will be limited to introducing frogs to curious markets. Introduction of frogging eco-tours that are guided by local community members will only be attempted if support is available for that aspect of CBE. Once the introduction of amphibians into NGR's list of tourist attractions is complete the lessons learned from this exercise will be used to introduce frogs as tourist attractions at other reserves. Amphibian survey and monitoring will form a large part of future studies.

5.3 Conclusion

This study has successfully contributed to amphibian diversity monitoring at NGR. It has also contributed to understanding how frogs use their habitats and how their distribution is affected by characteristics of these habitats. By implementing aspects of CBE this study has extended the benefits of amphibian diversity beyond academia to include ordinary people. The study demonstrates how the scientific community can contribute to enriching the lives of non-scientists and play a pivotal role in decreasing conflict between conservation and development objectives.

References

(African Zoology style of referencing)

Adams W, Aveling MR, Brockington D, Dickson B, Elliott J, Hutton J, Roe D, Vira B, Wolmer W. 2004. Biodiversity conservation and the eradication of poverty. *Science* 306 (5699): 1146–1149.

Adams W, Hulme D. 2001. Conservation and community: changing narratives, policies and practices in African conservation. In: Hulme D, Murphree MW (eds), *African wildlife and livelihoods. The promise and performance of community conservation.* Oxford: James Currey. pp 9–37.

Adams JS, McShane TO. 1992. *The myth of wild Africa: conservation without illusion*. Berkeley: University of California Press.

Alexander GJ, Harrison JA, Fairbanks DH, Navarro RA. 2004. Biogeography of the frogs of South Africa, Lesotho and Swaziland. In: Minter LR, Burger M, Harrison JA, Braack HH, Bishop PJ, Kloepfer D (eds), *Atlas and red data book of the frogs of South Africa, Lesotho and Swaziland*. SI/MAB Series #9. Washington: Smithsonian Institution. pp 31–47.

Allan DG, Harrison JA, Herremans M, Navarro RA, Underhill LG. 1997. Southern African geography: its relevance to birds. In: Harrison JA, Allan DG, Underhill JG, Herremans M, Tree AJ, Parker V, Brown CJ (eds), T*he Atlas of Southern African birds. Vol. 1.* Johannesburg: BirdLife South Africa. pp. lxv–ci.

Alvarez LW, Alvarez W, Asaro F, Michel HV. 1980. Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science* 208: 1095–1108.

Angulo A, Hoffmann M, Measey GJ. 2011. Introduction: conservation assessments of the amphibians of South Africa and the world. In: Measey GJ (ed), *Ensuring a future for South Africa's frogs: a strategy for conservation research.* SANBI Biodiversity Series 19. Pretoria: South African National Biodiversity Institute. pp 1–10.

Archibald JD, Clemens WA, Padian K, Rowe T, Macleod N, Barrett PM, Gale A, Holroyd P, Sues HD, Arens NC, Horner JR. 2010. Cretaceous extinctions: multiple causes. *Science 328*(5981): 973–973.

Backwell PR. 2016. *Aspects of reproduction in the leaf-foldind frog Afrixalus delicatus*

Johannesburg: University of the Witwatersrand, (Doctoral Dissertation).

Balmford A, Moore JL, Brooks T, Burgess N, Hansen LA, Williams P, Rahbek C. 2001. Conservation conflicts across Africa. *Science* 291(5513): 2616–2619.

Barrett CB, Brandon K, Gibson C, Gjertsen H. 2001. Conserving tropical biodiversity amid weak institutions. *BioScience* 51(6): 497–502.

Beebee, TJC, Griffiths RA. 2005. The amphibian decline crisis: a watershed for conservation biology? *Biological Conservation* 125: 271–285.

Bell RH. 1987. Conservation with a human face: conflict and reconciliation in African land use planning. In: Anderson D, Grove RH (eds), *Conservation in Africa: people, policies and practice.* Cambridge: Cambridge University Press. pp 79–101.

Bell RC, Drewes RC, Channing A, Gvoždík V, Kielgast J, Lötters S, Stuart BL, Zamudio KR. 2015. Overseas dispersal of Hyperolius reed frogs from Central Africa to the oceanic islands of São Tomé and Príncipe. *Journal of Biogeography* 42(1): 65–75.

Berkes F, 2004. Rethinking community-based conservation. *Conservation biology* 18(3): 621–630.

Bishop PJ, Angulo A, Lewis JP, Moore RD, Rabb GB, Moreno JG. 2012. The amphibian extinction crisis-what will it take to put the action into the amphibian conservation action plan? *SAPI EN. S. Surveys and Perspectives Integrating Environment and Society* (5.2).

Blair WF. 1961. Calling and spawning seasons in a mixed population of anurans. *Ecology* 42: 99–110.

Blaustein AR, Kiesecker JM. 2002. Complexity in conservation: lessons from the global decline of amphibian populations. *Ecology Letters* 5: 597–608.

Bickford D, Posa MR, Qie L, Campos-Arceiz A, Kudavidanage EP. 2012. Science communication for biodiversity conservation. *Biological Conservation* 151(1): 74–6.

Bond I, Frost PG. 2005. CAMPFIRE and Payments for Environmental Services. In *Workshop: payments for environmental services (pes)–methods and design in developed and developing countries*. Titisee: Germany. pp 15–18.

Botts EA, Erasmus BF, Alexander GJ. 2012. Methods to detect species range size change from biological atlas data: A comparison using the South African Frog Atlas Project. *Biological Conservation* 146(1): 72–80.

Botts EA, Erasmus BFN, Alexander GJ. 2013. Small range size and narrow niche breadth predict range contractions in South African frogs. *Global Ecology and Biogeography* 22(5): 567–76.

Botts EA, Erasmus BFN, Alexander GJ. 2015. Observed range dynamics of South African amphibians under conditions of global change. *Austral Ecology* 40: 309–317.

Brewer C. 2002. Outreach and partnership programs for conservation education where endangered species conservation and research occur. *Conservation Biology 16*(1): 4–6.

Bridges AS, Dorcas ME. 2000. Temporal variation in anuran calling behavior: implications for surveys and monitoring programs. *Copeia* 2000(2): 587–592.

Brosius JP. 2006. Between politics and poetics: narratives of dispossession in Sarawak, east Malaysia. In: by Biersack A, Greenberg JB (eds), *Reimagining Political Ecology*. Durham: Duke University Press. pp 281–324.

Brosius JP. 2010. Conservation trade–offs and the politics of knowledge. In: Leader-Williams N, Adams WM, Smith R J (eds), *Trade-offs in conservation: deciding what to save*. Chichester: Wiley-Blackwell. pp 311–328.

Carnie T. 2011. *Game reserve fence restored*. The Mercury, 28 October. http://www.iol.co.za/news/south-africa/kwazulu-natal/game-reserve-fence-restored-1.1167034 [accessed 05 March 2016].

Cayuela H, Arsovski D, Bonnaire E, Duguet R, Joly P, Besnard A. 2016. The impact of severe drought on survival, fecundity, and population persistence in an endangered amphibian. *Ecosphere* 7:(2).

CBD (Convention on Biological Diversity). 2011. *Strategic plan for biodiversity 2011–2020 and the Aichi Targets*. http:// www.cbd.int/sp/targets/ [accessed 7 November 2012].

Ceballos G, Ehrlich PR. 2002. Mammal population losses and the extinction crisis. *Science* 296: 904–907.

Channing A, van Dijk DE. 1995. Amphibia. In: Cowan GI (ed), *Wetlands of South Africa*. Pretoria: Department of Environmental Affairs and Tourism. pp 193–206.

Collins JP, Storfer A. 2003. Global amphibian declines: sorting the hypotheses. *Diversity and Distributions 9*(2): 89–98.

Crist E, Mora C, Engelman R. 2017. The interaction of human population, food production, and biodiversity protection. *Science* 356(6335): 260-4.

De Moor PP, Pooley E, Neville G, Barichievy J. 1977. The vegetation of Ndumo Game Reserve, Natal: A quantitative physiognomic survey. *Annals of the Natal Museum* 23: 239–272.

DEA (Department of Environmental Affairs) *see* South Africa. Department of Environmental Affairs.

Dickinson JL, Bonney R. 2012. *Citizen science: public collaboration in environmental research.* Ithaca: Cornell University Press.

Dickinson JL, Shirk J, Bonter D, Bonney R, Crain RL, Martin J, Phillips T, Purcell K. 2012. The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment 10*(6): 291–297.

Dickinson JL, Zuckerberg B, Bonter DN. 2010. Citizen science as an ecological research tool: challenges and benefits. *Annual Review of Ecology, Evolution, and Systematics* 41: 149–172.

Dorcas ME, Price SJ, Walls SC, Barichivich WJ. 2009. Auditory monitoring of anuran populations. In: Dodd Jr CK (ed), *Amphibian ecology and conservation: a hand book of techniques.* Oxford: Oxford University Press. pp 281–298.

Dressler W, Büscher B. 2008. Market triumphalism and the so-called CBNRM ‘crisis’ at the South African section of the Great Limpopo Transfrontier Park. *Geoforum* 39(1): 452–465.

Dressler W, Büscher BE, Schoon M, Brockington D, Hayes T, Kull CA, McCarthy J, Shrestha K. 2010. From hope to crisis and back again? a critical history of the CBNRM narrative. *Environmental Conservation* 37(1): 5–15.

Driver A, Maze K, Rouget M, Lombard AT, Nel J, Turpie JK, Cowling RM, Desmet P, Goodman P, Harris J, Jonas Z, Reyers B, Sink K, Strauss T. 2005. National spatial biodiversity conservation in South Africa (NSBA). *Strelitzia 17*. Pretoria: South African National Biodiversity Institute.

Droege S, Eagle P. 2005. Evaluating calling surveys. In: Lannoo M (ed), *Amphibian declines: The conservation status of United States species*. Berkeley: University of California Press. pp 314–19.

Du Preez LH, Carruthers VC. 2009. *A complete guide to the Frogs of Southern Africa*. Cape Town: Penguin Random House.

Du Preez LH, Carruthers VC. 2015. *A complete guide to the Frogs of Southern Africa*

[Mobile Application edition]. Cape Town: Penguin Random House.

Du Preez LH, Carruthers VC. 2017. *Frogs of Southern Africa*. Cape Town: Penguin Random House.

Duellman WE, Trueb L. 1986. *Biology of amphibians*. New York City: McGraw-Hill Publishing Company.

Fretwell SD, Lucas Jr HL. 1970. on territorial behavior and other factors influencing habitat distribution in birds. *Acta Biotheoretica: Mathematical and philosophical foundations of biological and biomedical science* 19: 16–36.

Frost DR. 2017. *Amphibian species of the world: an online reference.* Version 6.0. Electronic Database accessible at http://research.amnh.org/herpetology/amphibia/index.html. [accessed on 24 October 2017]

Frost DR, Grant T, Faivovich J, Bain RH, Haas A, Hadadd CFB, De Sá RO, Channing A, Wilkinson M, Donnellan SC, Raxworthy CJ, Campbell JA, Blotto BL, Moler PE, Drewes RC, Nussbaum RA, Lynch JD, Green DM, Wheeler WC. 2006. The Amphibian tree of life. *Bulletin of the American Museum of Natural History* 297:1–370.

Fuggle RF, Rabie MA. 2009*. Environmental management in South Africa*. Cape Town: Juta and Company (Pty) Ltd.

Grant R, Thomas V. 1998. *Sappi tree spotting: KwaZulu/Natal coast & midlands.* Johannesburg: Jacana.

Haddad CR. 2003. Fruit chafers (*Coleoptera: Scarabaeidae: Cetoniini*) of the Ndumo Game Reserve and Tembe Elephant Park, KwaZulu-Natal. *African Entomology* 11(1): 130–133.

Haddad CR, Dippenaar-Schoeman AS, Wesolowska W. 2006. A checklist of the non-acarine arachnids (Chelicerata: Arachnida) of the Ndumo Game Reserve, Maputaland, South Africa. *Koedoe* 49(2): 1–22.

Harcourt AH, Pennington H, Weber AW. 1986. Public attitudes to wildlife and conservation in the Third World. *Oryx* 20(3): 152–4.

Heyer WR, Bellin MS. 1973. Ecological notes on five sympatric *Leptodactylus* (Amphibia, Leptodactylidae) from Ecuador. *Herpetologica* 66–72.

Hill D, Fasham M, Tucker G, Shewry M, Shaw P. 2005. *Handbook of biodiversity* *methods: survey, evaluation and monitoring.* Cambridge: Cambridge University Press.

Hirai T, Matsui M. 1999. Feeding habits of the pond frog, *Rana nigromaculata*, inhabiting rice fields in Kyoto, Japan. *Copeia* 940–947.

Hof C, Araújo MB, Jetz W, Rahbek C. 2011. Additive threats from pathogens, climate and land-use change for global amphibian diversity. *NATURE 480*: 22.

Infield M. 1988. Attitudes of a rural community towards conservation and a local conservation area in Natal, South Africa. *Biological Conservation* 45(1):21–46.

IUCN (International Union for Conservation of Nature and Natural Resources). 2016. *Amphibians*. http://www.iucnredlist.org/initiatives/amphibians/analysis/geographic-patterns. [accessed 05 July 2017].

IUCN (International Union for Conservation of Nature and Natural Resources). 2017a. *The IUCN Red List of Threatened Species*. Version 2017–2. <http://www.iucnredlist.org>. [accessed 15 September 2017]

IUCN (The IUCN Red List of Threatened Species). 2017b. *IUCN Red List of Threatened Species*. Version 2017-2: Table 5. <www.iucnredlist.org>. [accessed 15 September 2017].

Jacobsen NHG. 1989. *A herpetological survey of the Transvaal.* Durban: University of Natal. (Thesis – PhD).

Jewitt D, Goodman PS, Erasmus BF, O'Connor TG, Witkowski ET. 2015. Systematic land-cover change in KwaZulu-Natal, South Africa: implications for biodiversity. *South African Journal of Science 111*(9–10): 01–09.

Jones JL. 2005. Transboundary conservation: development implications for communities in KwaZulu- Natal, South Africa. *International Journal of Sustainable Development and World Ecology* 12(3): 266–278.

Kamal AH, Mair GC. 2005. Salinity tolerance in superior genotypes of tilapia, *Oreochromis niloticus*, *Oreochromis mossambicus* and their hybrids. *Aquaculture* 247(1): 189–201.

Kellert SR, Mehta JN, Ebbin SA, Lichtenfeld LL. 2000. Community natural resource management: promise, rhetoric, and reality. *Society & Natural Resources 13*(8): 705–715.

Kiesecker JM, Blaustein, AR, Belden LK. 2001. Complex causes of amphibian population declines. *Nature* 410(6829): 681–684.

Kiss A. 2004. Is community-based ecotourism a good use of biodiversity conservation funds? *TRENDS in Ecology and Evolution* 19(5): p232–236.

Klooster D. 2000. Community forestry and tree theft in Mexico: resistance or complicity in conservation? *Development and Change* 31(1): 281–305.

Koekemoer M, Steyn HM, Bester SP. 2014. *Guide to plant families of southern Africa. Strelitzia 31.* Pretoria: South African Biodiversity Institute.

Lambiris AJL. 1988. *A review of the amphibians of Natal*. Lammergeyer Pietermaritzburg: Teeanem Printers.

Langtimm CA. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83: 2248–55.

Layne Jr JR, Lee RE. Adaptation of frogs to survive freezing. *Climate Research* 5(1): 53–59 DOI: 10.3354/cr005053

Lepš J, Šmilauer P. 2003. *Multivariate analysis of ecological data using CANOCO*. Cambridge: Cambridge University Press.

MacKenzie DL, Nichols JD, Lachman GB, Droege S, Royle JA, MacLeod N. 1997. The Cretaceous-Tertiary biotic transition. *Journal of the Geological Society* 154: 265–292.

Measey GJ. 2011. *Ensuring a future for South Africa's frogs: a strategy for conservation research.* SANBI Biodiversity Series 19. Pretoria: South African National Biodiversity Institute.

Measey GJ, Minter LR, Turner A. 2011a. Assessing status and trends. In: Measey GJ (ed), *Ensuring a future for South Africa's frogs: a strategy for conservation research.* SANBI Biodiversity Series 19. Pretoria: South African National Biodiversity Institute. pp 29–37.

Measey GJ, Vences M, Drewes RC, Chiari Y, Melo M, Bourles B. 2007. Freshwater paths across the ocean: molecular phylogeny of the frog *Ptychadena newtoni* gives insights into amphibian colonization of oceanic islands. *Journal of Biogeography* 34(1): 7–20.

Measey GJ, Weldon C, Morgan D, Channing A, Harvey J, Turner A. 2011b. Conservation and ecological studies. In: Measey GJ (ed), *Ensuring a future for South Africa's frogs: a strategy for conservation research.* SANBI Biodiversity Series 19. Pretoria: South African National Biodiversity Institute. pp 18–29.

Meer T, Schnurr MA. 2013. The community versus community-based natural resource management: the case of Ndumo Game Reserve, South Africa. *Canadian Journal of Development Studies* 34(4): 482–497.

Mendelson III JR, Lips KR, Gagliardo, RW, Rabb GB, Collins JP, Diffendorfer JE, Daszak P, Ibanez DR, Zippel KC, Lawson DP, Wright KM, Stuart SN, Gascon C, Da Silva HR, Burrowes PA, Joglar RL, La Marca E, Lotters S, Du Preez LH, Weldon C, Hyatt A, Rodriguezmahecha JV, Hunt S, Robertson H, Lock B, Raxworthy CJ, Frost DR, Lacy RC, Alford RA, Campbell JA, Parra-Olea G, Bolanos F, Domingo JJC, Halliday J, Murphy JB, Wake MH, Coloma LA, Kuzmin SL, Price, MS, Howell, KM, Lau M, Pethiyadoda R, Boone M, Lannoo MJ, Blaustein AR, Dobson, A, Griffiths RAL, Crump M, Wake DB, Brodie Jr ED. 2006. Confronting amphibian declines and extinctions. *Science* 313: 48.

Miller JA, Dunford AJ, Swana KA, Palcsu L, Butler M, Clarke CE. 2017. Stable isotope and noble gas constraints on the source and residence time of spring water from the Table Mountain Group Aquifer, Paarl, South Africa and implications for large scale abstraction. *Journal of Hydrology*.

Minter LR. 1995. The advertisement call and other aspects of the reproductive biology of *Breviceps adspersus* Peters (Anura, Microhylidae). *Madoqua* 19(1): 37–44.

Minter LR. 2003. Two new cryptic species of *Breviceps* (Anura: Microhylidae) from southern Africa. *African Journal of Herpetology* 52: 9–21.

Minter LR, Burger M, Harrison JA, Braack HH, Bishop PJ, & Kloepfer D (eds). 2004. *Atlas and red data book of the frogs of South Africa, Lesotho and Swaziland*. SI/MAB Series #9. Washington: Smithsonian Institution.

Minter LR, Netherlands EC, Du Preez LH. 2017. Uncovering a hidden diversity: two new species of Breviceps (Anura: Brevicipitidae) from northern KwaZulu-Natal, South Africa. *Zootaxa* 4300(2): 195–216.

Mittermeier RA, Turner WR, Larsen FW, Brooks TM, Gascon C. 2011. Global biodiversity conservation: the critical role of hotspots. In: Zachos FE, Habel JC (eds), *Biodiversity hotspots*. Berlin/Heidelberg: Springer. pp 3–22.

Morell V. 1999. Frogs: canaries in the hot zone? *Science* 284: 729.

Mucina L, Rutherford MC (eds). 2006. *The vegetation of South Africa, Lesotho, and Swaziland*. *Strelitzia 19*. Pretoria: South African National Biodiversity Institute.

Murphree MW. 2002. Protected areas and the commons. *Common Property Resource*

Digest 60: 1–3.

Netherlands, 2014. *Species diversity, habitat utilization and blood parasites of amphibians in and around Ndumo Game Reserve.* Potchefstroom: North-West University. (Masters Dissertation).

Newmark WD, Leonard NL, Sariko HI, Gamassa DG. 1993. Conservation attitudes of local people living adjacent to five protected areas in Tanzania. *Biological Conservation* 63(2): 177–83.

O'Connor TG, Kuyler P. 2009. Impact of land use on the biodiversity integrity of the moist sub-biome of the grassland biome, South Africa. *Journal of Environmental Management 90*(1): 384–395.

Passmore NI. 1978. *The vocalisations and aspects of the reproductive behaviour of the genus Ptychadena in South Africa*. Johannesburg: University of the Witwatersrand. (Thesis - Ph.D).

Patel K. 2006. Reconstructing the political boundary in the Lubombo Transfrontier Conservation and Resource Area. New Haven: Yale University. (Thesis - Unpublished)

Pérez JE, Nirchio M, Alfonsi C, Munoz C. 2006. The biology of invasions: the genetic adaptation paradox. *Biological Invasions* 8: 1115–1121.

Phaka FM, Netherlands EC, Kruger DJD, Du Preez LH. 2017. *A Bilingual field guide to the frogs of Zululand.* Suricata 3. Pretoria: South African National Biodiversity Institute.

Plenderleith TL, Smith KL, Donnellan SC, Reina RD, Chapple DG. 2015. Human-assisted invasions of Pacific Islands by *Litoria* frogs: A case study of the Bleating Tree Frog on Lord Howe Island. *PLoS ONE* 10(5): e0126287. https://doi.org/10.1371/journal.pone.0126287

Portik DM, Blackburn DC. 2016. The evolution of reproductive diversity in Afrobatrachia: A phylogenetic comparative analysis of an extensive radiation of African frogs. *Evolution* 70(9): 2017-32.

Poynton JC. 1964. The amphibia of southern Africa: a faunal study. *Annals of the Natal Museum* 17: 1–334.

Prauss ML. 2009. The K/Pg boundary at Brazos-River, Texas, USA—an approach by marine palynology. *Palaeogeography, Palaeoclimatology, Palaeoecology* 283: 195–215.

Pringle EL, Kyle RG. 2002. Checklists of the butterflies of the Ndumo. Tembe and Kosi

Bay Nature Reserves, KwaZulu-Natal, South Africa. *Three men in an Isuzu–Namaqualand* 18.

Protected Areas Act *see* South Africa.

Pyron RA. 2011. Divergence time estimation using fossils as terminal taxa and the origins of Lissamphibia. *Systematic Biology 60*(4): 466–481.

Rautenbach H. 2016. Drought and the weather: 2015/2016 in review. *FarmBiz* 2(2): 6–7.

Redford KH, Sanderson SE. 2000. Extracting humans from nature. *Conservation Biology* 14(5): 1362–1364.

Robertson DS, Lewis WM, Sheehan PM, Toon OB. 2013. K-Pg extinction patterns in marine and freshwater environments: the impact winter model. *Journal of Geophysical Research* 118: 1006-1014. doi:10.1002/jgrg.20086.

Roelants K, Gower DJ, Wilkinson M, Loader SP, Biju SD, Guillaume K, Moriau L, Bossuyt F. 2007. Global patterns of diversification in the history of modern amphibians. *Proceedings of the National Academy of Sciences 104*(3): 887–892.

Russell DJ, Thuesen PA, Thomson FE. 2012. A review of the biology, ecology, distribution and control of Mozambique Tilapia, *Oreochromis mossambicus* (Peters 1852)(Pisces: Cichlidae) with particular emphasis on invasive Australian populations. *Reviews in Fish Biology and Fisheries* 22(3): 533–554.

Saber PA, Dunson WA. 1978. Toxicity of bog water to embryonic and larval anuran amphibians. *Journal of Experimental Zoology* 204: 3.

Schoeman F, Newby TS, Thompson MW, Van den Berg EC. 2013. South African national land-cover change map. *South African Journal of Geomatics* 2: 94–105.

SANBI (South African National Biodiversity Institute). 2012. Vegetation map of South Africa, Lesotho and Swaziland [vector geospatial dataset] 2012. http://bgis.sanbi.org/ [accessed 26 October 2016].

Songorwa AN. 1999. Community-based wildlife management (CWM) in Tanzania: Are the communities interested? *World development* 27(12): 2061–2079.

South Africa. DEA (Department of Environmental Affairs). *2015. South Africa's 2015 national biodiversity strategy and action plan*. https://www.environment.gov.za/sites/default/files/docs/publications/SAsnationalbiodiversity_strategyandactionplan2015_2025.pdf [accessed 15 September 2017].

South Africa. DEA (Department of Environmental Affairs) 2017. National Environmental

Management: Biodiversity Act, 2004 (Act No. 10 of 2004): Biodiversity management plan for Pickergill's Reed Frog (*Hyperolius pickergilli*), 2017. (Notice 423). *Government gazette,* 40883: 184, 2 June.

South Africa. 2003. Protected Areas Act No. 57 of 2003

Stats SA (Statistics South Africa). 2012. *South Africa statistics.* Pretoria: Statistics South Africa.

Stats SA (Statistics South Africa). 2014. *Census 2011 provincial profile: Kwazulu-Natal*. Pretoria: Statistics South Africa.

Stats SA (Statistics South Africa). 2017. *Mid-year population estimates*. Pretoria: Statistics South Africa.

Stem CJ, Lassoie JP, Lee DR, Deshler DJ. 2003a. How 'Eco' is ecotourism? A comparative case study of ecotourism in Costa Rica. *Journal of Sustainable Tourism* 11(4): 322–347.

Stem CJ, Lassoie JP, Lee DR, Deshler DD, Schelhas JW. 2003b. Community participation in ecotourism benefits: the link to conservation practices and perspectives. *Society & Natural Resources* 16(5): 387–413.

Stuart SN, Chanson JS, Cox NA, Young BE, Rodrigues ASL, Fischman DL, Waller LR. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* 306: 1783–1786.

Tarrant J. 2015. *My first book of southern African frogs*. Cape Town: Struik Nature.

Ter Braak CJ, Šmilauer P. 2002. *Canoco 4.5: Reference manual and canodraw for windows. User's guide: Software form canonical community ordination (version 4.5).* Ithaca: Microcomputer Power.

Tinley KL, van Riet WT. 1981. *Proposals towards an environmental plan for KwaZulu*. Durban: KwaZulu Department of Agriculture and Forestry. (Unpublished report.)

Toft CA, 1985. Resource partitioning in amphibians and reptiles. *Copeia* 11: 1–21.

Tolley KA, Chase B, Forest F. 2008. Speciation and radiations track climate transitions since the Miocene Climatic Optimum: a case study of southern African chameleons. *Journal of Biogeography* 35: 1402–1414.

Uchida K, Kaneko T, Miyazaki H, Hasegawa S, Hirano T. 2000. Excellent salinity tolerance of

Mozambique Tilapia (*Oreochromis mossambicus*): elevated chloride cell activity in the branchial and opercular epithelia of the fish adapted to concentrated seawater. *Zoological Science* 17(2): 149–160.

UN (United Nations). 2000. *United Nations Millennium Development Goals*. http://www.un.org/millenniumgoals/ [accessed 16 September 2017].

UN DESA (United Nations, Department of Economic and Social Affairs, Population Division). 2017. *World population prospects: the 2017 revision, key findings and advance tables.* Working Paper No. ESA/P/WP/248. https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf [accessed 16 September 2017].

Wager VA. 1965. *The Frogs of South Africa*. London: Purnell & Sons.

Wake DB. 1991. Declining amphibian populations. *Science* 253(5022): 860–860.

Wake DB, Vredenburg VT. 2008. Colloquium paper: are we in the midst of the sixth mass extinction? A view from the world of amphibians. *Proceedings of the National Academy of Sciences of the United States of America* 105**:** 11466–11473.

Weldon C, Du Preez LH, Hyatt AD, Muller R, Speare R. 2004. Origin of the amphibian chytrid fungus. *Emerging infectious diseases 10*(12): 2100.

Welicky RL, De Swardt J, Gerber R, Netherlands EC, Smit NJ. 2017. Drought-associated absence of alien invasive anchorworm, *Lernaea cyprinacea* (Copepoda: Lernaeidae), is related to changes in fish health. *International Journal for Parasitology: Parasites and Wildlife.*

Vitt LJ, Caldwell JP. 2009. *Herpetology: an introductory biology of amphibians and reptiles*. Burlington: Academic Press/Elsevier.

Appendices

Appendix A: Permits

EZEMVELO KZN WILDLIFE

Conservation, Partnerships & Ecotourism

ORIGINAL

ORDINARY PERMIT

Fee:	R 50.00	Permit No:	OP 4092/2016
Receipt No:	4147/2016	Contact:	Miss S.M. Hughes

This permit is issued in pursuance of the provisions of the Nature Conservation Ordinance No 15 of 1974 , Chapter 7 and the Regulations framed thereunder.

The permit is issued to:

ID Number: 8905155123088

Mr Edward Charles Netherlands	**Residential Address**
North-West University	**North-West University**
Zoology	**Zoology**
Private Bag X6001	**Room G16, Building EG**
Potchefstroom	**Potchefstroom Campus**
2530	**Potchefstroom**
	2531

In the capacity of Researcher

To Collect, Extract blood samples, Release and Export the following species of Amphibians Invertebrates and Reptiles

ALL SPECIES OF FROGS

10 (Ten) per species per protected area or other locality throughout KwaZulu-Natal EXCLUDING KZN Wildlife protected areas but including the following protected areas: Tembe Elephant Park, Vernon Crookes Nature Reserve, Ndumo Game Reserve, Royal Natal National Park, Hluhluwe-iMfolozi Park and iSimangaliso Wetland Park.

REPTILES

10 (Ten) per species per protected area or other locality throughout KwaZulu-Natal EXCLUDING KZN Wildlife protected areas but including the following protected areas: Tembe Elephant Park, Vernon Crookes Nature Reserve, Ndumo Game Reserve, Royal Natal National Park, Hluhluwe-iMfolozi Park and iSimangaliso Wetland Park.

Please read the Terms and Conditions under which this Permit is issued

ISSUED at PIETERMARITZBURG, KwaZulu-Natal, on 08 November 2016

for CHIEF EXECUTIVE

Permit Holder

EZEMVELO KZN WILDLIFE PERMITS OFFICE
PO Box 13053, Cascades, 3202, Pietermaritzburg, KwaZulu-Natal.
Tel +27 33 845 1320 / 1324. Fax: +27 33 845 1747. Fax to Email: 086 529 3320
Email: permits@kznwildlife.com. Website: www.kznwildlife.com

OP 4092/2016 ***Page 1 of 4***

EZEMVELO KZN WILDLIFE

Conservation, Partnerships & Ecotourism

ORIGINAL

INVERTEBRATE

10 (Ten) per species per protected area or other locality throughout KwaZulu-Natal EXCLUDING KZN Wildlife protected areas but including the following protected areas: Tembe Elephant Park, Vernon Crookes Nature Reserve, Ndumo Game Reserve, Royal Natal National Park, Hluhluwe-iMfolozi Park and iSimangaliso Wetland Park.

TERMS AND CONDITIONS UNDER WHICH THIS PERMIT IS ISSUED

1. It is valid only:

   (i) from : 08 November 2016
   to : 07 November 2017

   (ii) in the original

   (iii) if all **4** pages are signed by the permit holder named above

   (iv) to the permit holder named above and the following Nominees :

   Prof. L.H du Preez

   Dr D Kruger

   Dr C. Cook

   Dr J Van As

   Dr C Weldon

   J. Reeder

   Mr W. Pretorius

   Mr F Phaka

2. By signing the permit or licence the holder accepts, and agrees to comply with the conditions under which it is issued.

3. Permit to be returned to E KZN Wildlife, P O Box 13053, Cascades, 3202, upon expiry for renewal or cancellation.

4. Permit shall be carried by holder, or the specified nominees, at all times during use.

5. Outside of E KZN Wildlife areas, use of this permit is subject to landowner's or controlling

Please read the Terms and Conditions under which this Permit is issued

ISSUED at PIETERMARITZBURG, KwaZulu-Natal, on 08 November 2016

for CHIEF EXECUTIVE

Permit Holder

EZEMVELO KZN WILDLIFE PERMITS OFFICE
PO Box 13053, Cascades, 3202, Pietermaritzburg, KwaZulu-Natal.
Tel +27 33 845 1320 / 1324. Fax: +27 33 845 1747. Fax to Email: 086 529 3320
Email: permits@kznwildlife.com. Website: www.kznwildlife.com

ORIGINAL

EZEMVELO KZN WILDLIFE

Conservation, Partnerships & Ecotourism

authority's written permission.

6. Prior to collecting in areas under the control of the E KZN Wildlife the holders shall contact the Officer-in-Charge of the area at least 48 (Forty-eight) hours before commencing, and shall comply with any conditions which the Officer may impose at his discretion. The officer may refuse collection or capture at his or her discretion.

7. At least one representative specimen (preferably at least one male and one female) of each species collected from each locality must be lodged with a recognised South African museum/herbarium. Holotype specimens, and half the number of paratype specimens, of any new species MUST BE DEPOSITED with a recognised South African museum/herbarium, and may only leave South Africa on a loan basis. These specimens are to be deposited in the SA museums within a year of publishing the description of the new species. The holder shall provide the Chief Executive Officer, KZNNCS with the name of the museum at which the specimens have been lodged, and the accession number of each specimen. This condition relates to unavoidable by-catch of non-target organisms as well.

8. A copy or copies of any publication arising from the authority herein contained will be made available to E KZN Wildlife.

9. Should renewal of this permit be desired, a minimum of one month's notice is required.

10. (i) Reserving accommodation within E KZNWildlife areas is entirely the responsibility of the permit holder. Booking is obtainable at the Central Booking Office, Telephone 033 8451000.(ii) Any assistance required from Board staff will be subject to other demands on the Officer's time and must be arranged in advance with him/her.

11. This permit is valid only if an export/import permit has been issued by the export/import province/country if the legislation applicable in such province/country prescribes such permit.

12. Valid for one consignment only. .

13. Holders shall provide the Chief Executive, with a named list of every specimen collected (including the class, order, family, gender and age), the geographical co-ordinates (to seconds accuracy) of each collection locality and dates of collection, as laid out in the following table. A Global Positioning System with the WGS84 Datum should be used wherever possible to determine the geographical co-ordinates of the collection sites; please state the method used.

14. SPECIMEN (museum Accession) - COLLECTION DATE (ddmmyy) - SPECIES - LOCALITY - LATITUDE (Seconds Accuracy) - LONGITUDE (Seconds Accuracy).
Holders are requested to provide additional information, such as the habitat in which each specimen was collected and abundance or relative abundance data (providing standardised sampling methods are used) with the list.

15. The transportation of any live specimen by air shall be done in accordance with the

Please read the Terms and Conditions under which this Permit is issued

ISSUED at PIETERMARITZBURG, KwaZulu-Natal, on 08 November 2016

for CHIEF EXECUTIVE

Permit Holder

EZEMVELO KZN WILDLIFE PERMITS OFFICE
PO Box 13053, Cascades, 3202, Pietermaritzburg, KwaZulu-Natal.
Tel +27 33 845 1320 / 1324. Fax: +27 33 845 1747. Fax to Email: 086 529 3320
Email: permits@kznwildlife.com. Website: www.kznwildlife.com

ORIGINAL

EZEMVELO KZN WILDLIFE

Conservation, Partnerships & Ecotourism

International Air Transport Association live animals regulations and any other Act relevant to the transport, keeping, handling, transport, care and/or welfare of the said species.

16. No collecting is permitted within the road reserve which is a strip 30 (thirty) metres either side of a public road, no matter how small or remote the road may be.

17. No collecting is permitted in the wilderness areas within the Protected Area. For confirmation of boundaries of the wilderness area contact the Officer in Charge.

18. No specimens collected or captured or exported under this permit may be sold.

19. If possible, dead by-catch is to be distributed to the relevant experts for those groups in South Africa under the same conditions of this permit. Please enclose a copy of this permit and the locality and field data associated with the by-catch with the by-catch specimens.

20. This permit/licence/certificate is issued subject to compliance with all other relevant legislation and does not preclude the permit holder from adherence thereto.

Please read the Terms and Conditions under which this Permit is issued

ISSUED at PIETERMARITZBURG, KwaZulu-Natal, on 08 November 2016

for CHIEF EXECUTIVE

Permit Holder

EZEMVELO KZN WILDLIFE PERMITS OFFICE
PO Box 13053, Cascades, 3202, Pietermaritzburg, KwaZulu-Natal.
Tel +27 33 845 1320 / 1324. Fax: +27 33 845 1747. Fax to Email: 086 529 3320
Email: permits@kznwildlife.com. Website: www.kznwildlife.com

Appendix B: Certificates

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Private Bag X6001, Potchefstroom,
South Africa, 2520

Tel: (018) 299-4900
Faks: (018) 299-4910
Web: http://www.nwu.ac.za

Institutional Research Ethics Regulatory Committee
Tel: +27 18 299 4849
Email : Ethics@nwu.ac.za

ETHICS APPROVAL CERTIFICATE OF STUDY

Based on approval by **AnimCare Animal Research Ethics Committee (AREC-130913-015) on 27/10/2016** after the meeting held on **27/10/2016**, the North-West University Institutional Research Ethics Regulatory Committee (NWU-IRERC) hereby **approves** your study as indicated below. This implies that the NWU-IRERC grants its permission that provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: **Amphibian diversity and Community-Based Ecotourism in Ndumo Game Reserve, South Africa.**

Study Leader/Supervisor: **Prof Louis du Preez**
Student: **Mr Fortunate M Phaka**

Ethics number:

N	W	U	-	0	0	3	4	8	-	1	6	-	A	5
Institution				Study Number						Year			Status	

Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application Type: New Application - Large Project

Commencement date: 2016-10-27 **Category:** 1

Continuation of the study is dependent on receipt of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation up to a maximum period of three years.

Special conditions of the approval (if applicable):

- Any research at governmental or private institutions, permission must still be obtained from relevant authorities and provided to the AnimCare. Ethics approval is required BEFORE approval can be obtained from these authorities.

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following:

- *The study leader (principle investigator) must report in the prescribed format to the NWU-IRERC via AnimCare:*
  - *annually (or as otherwise requested) on the monitoring of the study, and upon completion of the study*
  - *without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.*
- *Annually a number of studies may be randomly selected for an external audit.*
- *The approval applies strictly to the proposal as stipulated in the application form. Would any changes to the proposal be deemed necessary during the course of the study, the study leader must apply for approval of these amendments at the AnimCare, prior to implementation. Would there be deviated from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.*
- *The date of approval indicates the first date that the study may be started.*
- *In the interest of ethical responsibility the NWU-IRERC and AnimCare retains the right to:*
  - *request access to any information or data at any time during the course or after completion of the study;*
  - *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process.*
  - *withdraw or postpone approval if:*
    - *any unethical principles or practices of the study are revealed or suspected,*
    - *it becomes apparent that any relevant information was withheld from the AnimCare or that information has been false or misrepresented,*
    - *the required amendments, annual (or otherwise stipulated) report and reporting of adverse events or incidents was not done in a timely manner and accurately,*
    - *new institutional rules, national legislation or international conventions deem it necessary.*
- *AnimCare can be contacted for further information or any report templates via Ethics-AnimCare@nwu.ac.za or 018 299 2197.*

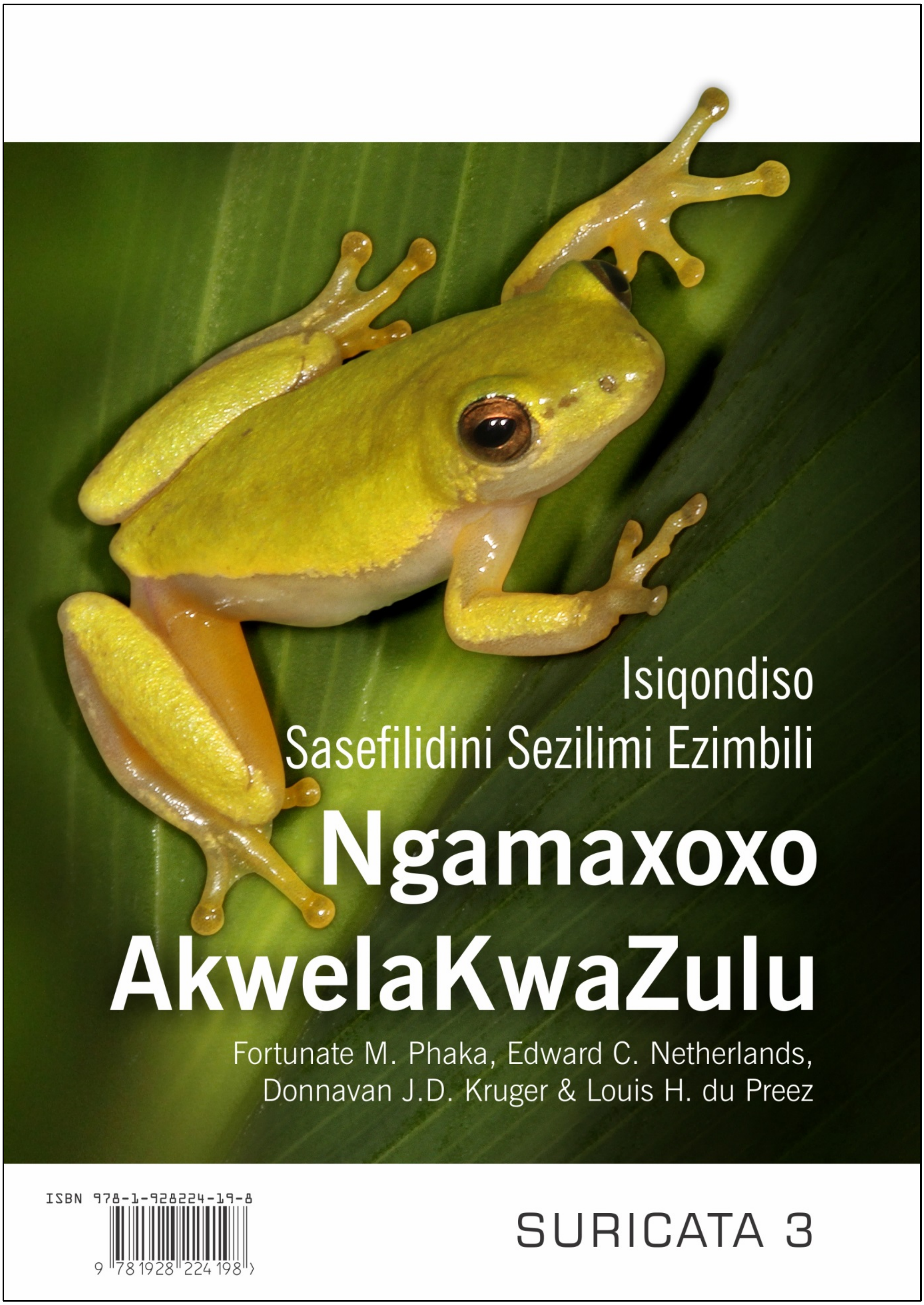
The IRERC would like to remain at your service as scientist and researcher, and wishes you well with your study. Please do not hesitate to contact the IRERC or AnimCare for any further enquiries or requests for assistance.

Yours sincerely

Prof LA Du Plessis
Digitally signed by Prof LA Du Plessis
Date: 2016.11.08 10:53:18 +02'00'

Prof Linda du Plessis
Chair NWU Institutional Research Ethics Regulatory Committee (IRERC)

Appendix C: Published or Submitted Research Outputs



SURICATA 3

Isiqondiso Sasefilidini Sezilimi Ezimbili

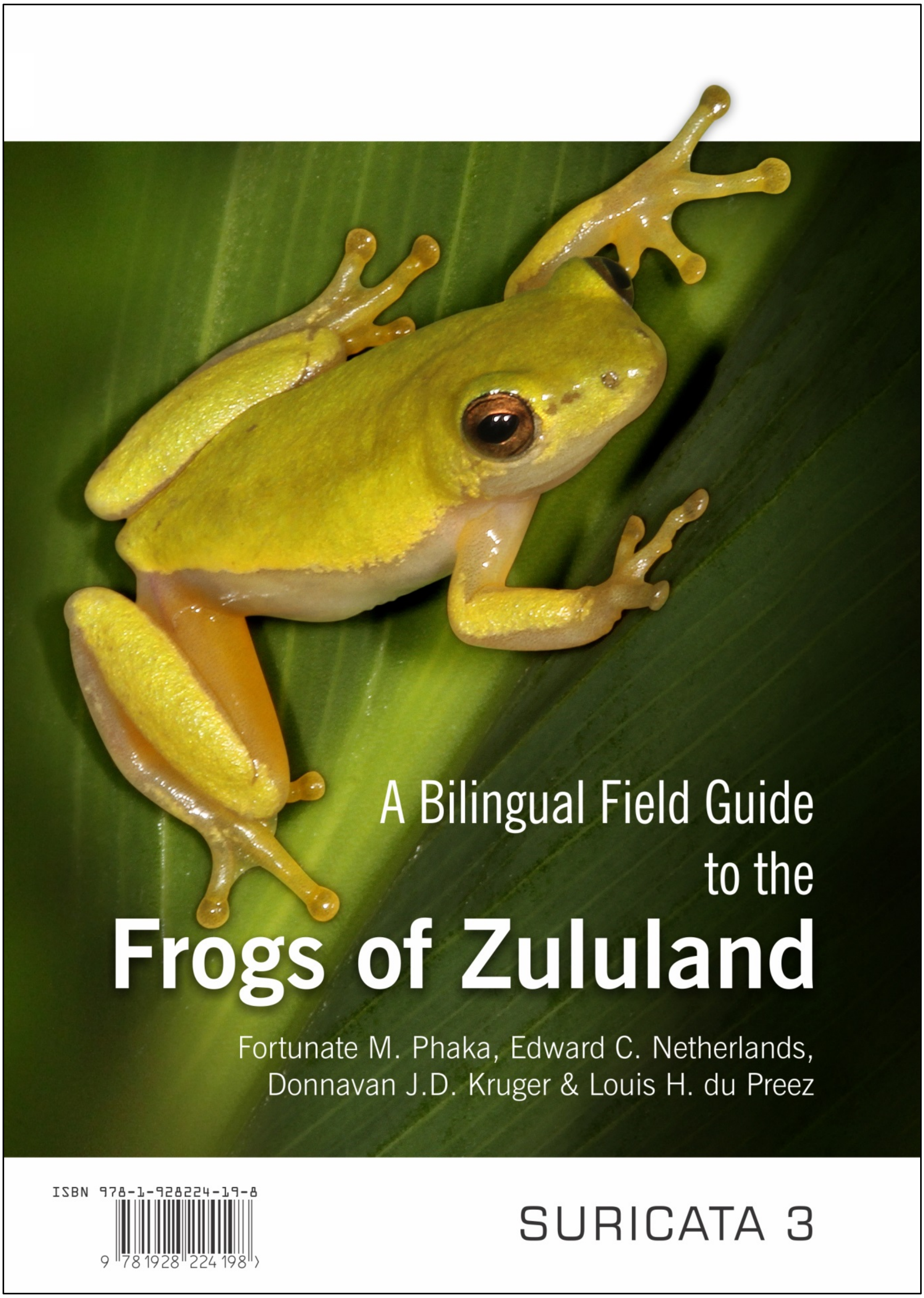
Ngamaxoxo AkwelaKwaZulu

Abalobi:
Fortunate M. Phaka[1]
Edward C. Netherlands[1,2]
Donnavan J.D. Kruger[3]
&
Louis H. du Preez[1,4]

[1] Unit for Environmental Sciences and Management, North-West University, Potchefstroom, 2520, South Africa
[2] Laboratory of Aquatic Ecology, Evolution and Conservation, University of Leuven, Charles Debériotstraat 32, B-3000 Leuven, Belgium
[3] School for Mathematics, Science and Technology Education, North-West University, Potchefstroom, 2520, South Africa
[4] South African Institute for Aquatic Biodiversity, Somerset Street, Grahamstown 6139

SANBI
Biodiversity for Life
South African National Biodiversity Institute

Pretoria
2017


A Bilingual Field Guide
to the
Frogs of Zululand
Fortunate M. Phaka, Edward C. Netherlands,
Donnavan J.D. Kruger & Louis H. du Preez
ISBN 978-1-928224-19-8
SURICATA 3

SURICATA 3

A Bilingual Field Guide to the

Frogs of Zululand

By:
Fortunate M. Phaka[1]
Edward C. Netherlands[1,2]
Donnavan J.D. Kruger[3]
&
Louis H. du Preez[1,4]

[1] Unit for Environmental Sciences and Management, North-West University, Potchefstroom, 2520, South Africa
[2] Laboratory of Aquatic Ecology, Evolution and Conservation, University of Leuven, Charles Debériotstraat 32, B-3000 Leuven, Belgium
[3] School for Mathematics, Science and Technology Education, North-West University, Potchefstroom, 2520, South Africa
[4] South African Institute for Aquatic Biodiversity, Somerset Street, Grahamstown 6139

SANBI
Biodiversity for Life
South African National Biodiversity Institute

Pretoria
2017

Appendix D: Conference contributions

1. Amphibian Conservation Research Symposium 2016:

ACRS
Amphibian Conservation Research Symposium 42

TALK ABSTRACTS

Community-Based Ecotourism in Ndumo Game Reserve: A Pilot Project for Promoting Local Economic Development and Amphibian Conservation.

Fortunate Phaka[1], Edward Netherlands, Donnovan Kruger, Louis du Preez

[1]*North-West University*

Communities living near nature reserves are often poor and also oblivious of conservation issues. Amphibians are increasingly under threat of extinction and yet there is little sentiment towards their conservation. Community-based ecotourism (CBE) presents a means of satisfying development and conservation objectives. This study aims to achieve those objectives through training members of communities near Ndumo Game Reserve to become frogging guides. It additionally seeks to promote information and communications technology (ICT) by using a mobile phone application as an aid for guide training and the subsequent frogging safaris. Through frogging safaris the locals can then establish a direct link between their livelihoods and the lives of amphibians in general and frogs in particular. Thus encouragement of frog conservation is provided partly through economic gain. Regular surveys will be undertaken to gauge public opinion about the importance frogs in order to measure the effectiveness of this project in promoting frog conservation within the local community. These surveys will begin before training of the guides commences and continue until frogging safaris occur regularly in Ndumo Game Reserve. This study will serve as a pilot for training local frogging guides and instilling a conservation ethic in them and their communities. Its success in Ndumo Game Reserve will result in the project being rolled out to various communities near reserves across South Africa.

#ACRS2016

2. 13th Conference of the Herpetological Association of Africa 2017:

Amphibian diversity and community-based ecotourism in Ndumo Game Reserve, South Africa

FORTUNATE M. PHAKA[1]*, DONNAVAN J.D. KRUGER[1], EDWARD C. NETHERLANDS[1,2] & LOUIS H. DU PREEZ[1,3]

[1]African Amphibian Conservation Research Group, Unit for Environmental Sciences and Management, North-West University, Potchefstroom, South Africa; [2]Laboratory of Aquatic Ecology, Evolution and Conservation, University of Leuven, Leuven, Belgium; [3]South African Institute for Aquatic Biodiversity, Grahamstown, South Africa.

Amphibians are declining at alarming rates globally. In comparison with other vertebrates, amphibians are at the forefront of the current extinction event. Conservation areas are mainly areas of high species richness and this is evident at Ndumo Game Reserve (NGR). Dense human population generally correlates positively with high species richness, and consequently

high human population numbers are associated with increased threat to biodiversity. This trend is also prevalent at NGR as it falls within an area that is characterised by high human activity, and communities surrounding NGR are mostly rural and dependent on the reserve for resources. Pressures resulting from high human population numbers are often cited as factors contributing to rapid amphibian declines. The conflict between conservation and development hampers attempts at effectively curbing the ongoing biodiversity loss. Community-based ecotourism or a community-based conservation project is a way of achieving development and conservation objectives simultaneously.

3. Amphibian Conservation Research Symposium 2017:

The golden tree frog (*Phytotriades auratus*) in Venezuela: what do we know so far and what remains to be known?

Gilson A. Rivas[1], **Mayke De Freitas**[2], Tito R. Barros[1], Luis Sibira[1] & Jorge M. González[3]

[1]Museo de Biología, Facultad Experimental de Ciencias, Universidad de Zulia, Venezuela.

[2]Cambridge, UK.

[3]Department of Plant Sciences, California State University, Fresno, CA 93740-8033.

Email: maykef@gmail.com

Phytotriades auratus is a frog known from four small summits in Trinidad and Península de Paria, Venezuela, where a new population was discovered in Cerro Humo in 2015. Other localities outside Paria have been surveyed over the last two years, following the distribution of the tank bromeliad *Glomeropitcairnia erectiflora*, a known host plant of *P. auratus*. The discovery of *P. auratus* in Venezuela could help solve one of the most puzzling mysteries of herpetology in the country. In 1950, two frogs were collected in Cerro Copey, Margarita Island, matching the description of *P. auratus*; the specimens were lost and a reliable description of the 'Copey frog' was never done. A 2017 visit to Cerro Copey did not result in new collections of the so-called 'Copey frog', but of another sympatric organism: the cockroach *Dryadoblatta scotti,* was found inside a *G. erectiflora* plant. The same cockroach specimen was also found by us in Cerro Humo. This cockroach appears to have the same distribution of *P. auratus*, and, as this one, was considered an endemic to Trinidad for many years. In this work we contribute with new localities that extend the geographical reach of Paria Peninsula westward and propose using VANTS and camera traps to explain the distribution of *G. erectiflora* and monitor the *P. auratus* respectively.

Amphibian diversity and Community-Based Ecotourism in Ndumo Game Reserve, South Africa

Fortunate M. Phaka[1], Edward C. Netherlands[1,2] & Louis H. Du Preez[1,3,4]

[1]African Amphibian Conservation Research Group, Unit for Environmental Sciences and Management, North-West University, Potchefstroom, South Africa

[2]Laboratory of Aquatic Ecology, Evolution and Conservation, University of Leuven, Leuven, Belgium

[3]South African Institute for Aquatic Biodiversity, Grahamstown, South Africa

[4]Corresponding author. E-mail: Louis.DuPreez@nwu.ac.za

Email: mafetap@gmail.com

Amphibian diversity is declining at an alarming rate globally. Survey and monitoring of amphibian communities is lax, yet vital to their conservation and understanding of their decline. Conservation areas harbour a lot of the anuran species richness along with a diversity of other taxa. Dense human population generally correlates positively with high biodiversity, and consequently high human population numbers are associated with increased threat to biodiversity. This trend is evident at Ndumo Game Reserve (NGR) which falls within the internationally recognised Maputaland-Pondoland-Albany Biodiversity Hotspot and is surrounded by rapid growing and primarily rural settlements where subsistence agriculture still predominates. The pressure on biodiversity grows as the human population increases and so does the risk to human wellbeing. A threat to biodiversity translates into a threat to the integrity of ecosystems on which people and wildlife depend.

The conflict between conservation and development hampers attempts at effectively curbing the ongoing biodiversity loss. Community-based conservation initiatives, which include community-based ecotourism (CBE), present a means of satisfying both development and conservation objectives. This study investigates various aspects of amphibian diversity at NGR. Results from this investigation are translated into a community-based conservation initiative for NGR. The study additionally promotes information and communications technology by using a mobile phone application as an aid for rolling out the initiative. This initiative serves as a pilot for introducing CBE through amphibian diversity on a larger scale across South Africa.

4: Joint Forum Biodiversity Information Management & Foundational Biodiversity Information Programme 2017:

The Natural Science Collection Facility
(short presentations)

Facilitator: Wayne Florence

Time	Session title		Presenters
11:00–12:00	**Talk 1:**	The Natural Science Collections Facility: Specimen Data Objectives	Michelle Hamer
	Talk 2:	Update on the digitising of the Killick Herbarium: feedback on the vision, progress and challenges	Boyd Escott
	Talk 3:	The National Collections of Fungi: The portal for phytopathogenic fungi from South Africa	Adriana Jacobs-Venter
	Questions and discussion		

Use, application and impact of biodiversity data: Challenges and opportunities
(short presentations)

Facilitator: Michelle Hamer

Time	Session title		Presenters
12:00–13:00	**Talk 1:**	Biodiversity informatics: Meeting sustainable development challenges for fisheries in the face of climate change in southern Africa	Fatima Parker-Allie
	Talk 2:	Towards expanding the South African Rhizobium Culture Collection (SARCC) as a genetic resource and its application in sustainable agriculture.	Ahmed Idris Hassen
	Talk 3:	Bridging the gap: Making amphibian biodiversity data relatable in South Africa	Fortunate M. Phaka
	Questions and discussion		
13:00–13:45	LUNCH		

4 | Joint Biodiversity Information Management & Foundational Biodiversity Information Programme Forum, 14–17 August 2017

Bridging the gap with A Bilingual Field Guide to The Frogs of Zululand

Fortunate M. Phaka[1], Edward C. Netherlands[1,2], Donnavan J.D. Kruger[3], and Louis H. du Preez[1,4]

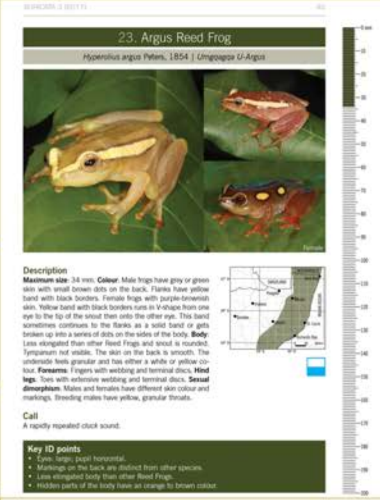
Introduction:
An understanding of biodiversity data by non-scientists is vital to success of conservation initiatives. This understanding is low as biodiversity data is often packaged in isolation of the intended recipients. This bilingual field guide to the frogs of Zululand is a book representing a novel way of presenting biodiversity data to non-scientists by using their perception of frogs as a point of departure for a book written in their own language. The book is additionally written in English in order to reach a wider audience and further bridge the gap in in understanding of frogs.

Aims:
- Study how Zululand community relates to frogs.
- Present Zululand frog diversity data within the context of the Zululand people.
- Increase understanding of frogs and dispel misconceptions in a non-confrontational way.

| Scientific & Technical Editor: Yolande Steenkamp | Translator (English to isiZulu): Manzo Khulu | Proofreader (English): Alicia Grobler |
| Design & Layout: Elizma Fouché | Cover photograph: Edward C. Netherlands |

SANBI
Biodiversity for Life
South African National Biodiversity Institute

Obtainable from: SANBI Bookshop, Private Bag X101, Pretoria, 0001 South Africa
Tel.: +27 12 843 5000
E-mail: bookshop@sanbi.org.za
Website: www.sanbi.org



Methods:

We held consultations with members of the Zululand community in order to document and study their cultural and personal perceptions of frogs.

Zululand frog biodiversity data is then presented using lessons learned about the Zululand community's perception of frogs as a context for explanations.

This information about frogs is presented using the two most prevalent languages in the Zululand region (English and isiZulu).

These consultations were also used for formulating new isiZulu frog names and modification of existing names.

Results:
A Bilingual Guide to the Frogs of Zululand is the main result of this project with all other outcomes contained within this book. The Zululand community does not commonly use individual names for different frog species. With the help of the community 58 isiZulu frog species names were formulated. Thirty species' names were newly formed, while 28 names were modified from My first book of southern African frogs by Tarrant (2015).

IsiZulu frog names generally refer to groupings of species based on similarities in behavior:
- 'Umgqagqa' generally refers to Reed Frogs or Leaf-folding frogs (Hyperoliidae)
- 'Isinana' generally refers to fossorial frogs (Breviceptidae and Hemisotidae)
- 'Idwi' generally refers to aquatic frogs (Pipidae)
- 'Ixoxo' generally refers to species with granular or warty skins (Bufonidae)
- 'Iselesele' generally refers to the smoother skinned species. This also includes other species not covered by the above names.

Conclusion:
The book contributes to making frog biodiversity data relatable to non-scientists. Furthermore, it bridges the gap in development of indigenous South African languages. The amphibian conservation agenda is furthered through novel means. A sense of ownership towards this book was also instilled in members of the Zululand community through participation in the early stages of its creation.

Affiliations:
[1] African Amphibian Conservation Research Group, Unit for Environmental Sciences and Management, North-West University, Potchefstroom, South Africa
[2] Laboratory of Aquatic Ecology, Evolution and Conservation, University of Leuven, Leuven, Belgium
[3] Faculty of Education, North-West University, Potchefstroom, South Africa
[4] South African Institute for Aquatic Biodiversity, Grahamstown, South Africa

References:
1. Alexander, G.J., Harrison, J.A., Fairbanks, D.H. & Navarro, R.A. 2004. Biogeography of the frogs of South Africa, Lesotho and Swaziland In: Atlas and Red Data Book of the Frogs of South Africa, Lesotho and Swaziland, (eds) L.R. Minter, M. Burger, J.A. Harrison, H.H. Braack, P.J. Bishop & D. Kloepfer. SI/MAB Series #9, pp. 31–47. Smithsonian Institution, Washington, DC.
2. Carruthers, V. & Du Preez, L.H. 2011. Frogs & frogging in South Africa. Cape Town: Struik Nature.
3. Channing, A., Schmitz, A., Burger, M. & Kielgast, J. 2013. A molecular phylogeny of African Dainty Frogs, with the description of four new species (Anura: Pyxicephalidae: Cacosternum). Zootaxa 3701.5: 518–550.
4. Conradie, W., Du Preez, L.H., Smith, K. & Weldon, C. 2006. Field guide to the frogs and toads of the Vredefort Dome World Heritage Site. Potchefstroom: North-West University.
Du Preez, L.H. & Carruthers, V.C. 2009. A complete guide to the frogs of southern Africa. Cape Town: Random House Struik.
5. Frost, D.R. 2016. Amphibian species of the world: an online reference. Available at http://research.amnh.org/herpetology/amphibia/index.html. Archived by WebCite at http://www.webcitation.org/6hHjciTTex on 5 May 2016.
6. Jewitt, D., Goodman, P.S., Erasmus, B.F., O'Connor, T.G. & Witkowski, E.T. 2015. Systematic land-cover change in KwaZulu-Natal, South Africa: implications for biodiversity. South African Journal of Science, 111,9-10: 01–09.
7. Minter, L.R., Burger, M., Harrison, J.A., Braack, H.H., Bishop, P.J. & Kloepfer, D., eds. 2004. Atlas and Red Data Book of the frogs of South Africa, Lesotho and Swaziland. SI/MAB Series #9. Washington, DC: Smithsonian Institution.
8. Poynton, J.C. 1964. The amphibia of southern Africa: a faunal study. Annals of the Natal Museum 17:1–334.

5. National Wetlands Indaba 2017:

SESSION 10	PARALLEL PRESENTATION / WORKSHOP SESSION			
	13:30 – 15:30	**REGIONAL DRIVERS OF ECOSYSTEM CHANGE (a)**	**WETLAND CONSERVATION (b)**	**WORKSHOP 2 (c)**
10.1(a,b&c)	13:30 – 13:45	The impact of climate change and climate variability on coastal wetland ecosystem dynamics F. Fortune	A coastal specialist – Pickersgill's Reed Frog – as a flagship for wetland conservation and research in KwaZulu-Natal J. Tarrant	**TOWARDS A DEPARTMENT OF WATER AND SANITATION WETLAND POLICY**
10.2(a,b&c)	13:45 – 14:00	The origin of endorheic bedrock pans on the African Erosion Surface along the Southern Cape Coast, South Africa. S. Ellery	Pickersgill's Reed Frog monitoring and community engagement in response to conservation interventions at coastal wetlands in eThekwini J. Magwaza	
10.3(a,b&c)	14:00 – 14:15	The role of the in situ weathering of dolerite on the formation of a peatland: the origin and evolution of Dartmoor Vlei in the KwaZulu-Natal Midlands, South Africa F. Ellery	Bridging the gap: Making Amphibian Biodiversity Data Relatable in South Africa F. Phaka	
10.4(a,b&c)	14:15 – 14:30	Investigating the processes of erosion and sediment yield at different scales in commercial forestry: A case study at Two Streams, KwaZulu-Natal J. Gillham	Do too many chefs spoil the broth? Towards a consolidated Act for wetland conservation - a critical analysis B. Lemine	
10.5(a,b&c)	14:30 – 14:45	The water balance dynamics of Soetendalsvlei – the southern-most lake on the Agulhas Plain, South Africa. M. Carolissen	Open session	

Appendix E: Survey Questionnaire for finding out about interest in frogs as a tourist attraction from Ndumo Game Reserve's field guides

1. How often do guests ask about frogs or request to see frogs when booking a safari?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Never Very Often

2. How often are guests intrigued by frog advertisement calls while on safari?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Never Very Often

3. How often do guests ask frog related questions while on safari?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Never Very Often

4. Guides' willingness to learn about frogs and include them in guiding repertoire.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Not Willing Very Willing

5. Guides level of knowledge about frogs.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Very Low Very High