THE EFFECT OF LAND USE ON THE SPECIES COMPOSITION OF AMPHIBIANS IN NORTH EASTERN KWAZULU-NATAL

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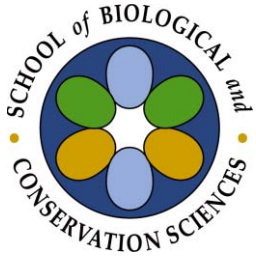

ABSTRACT

Global declines in amphibian species have directed research towards investigating why this is happening. One of the major causes of these declines is the fragmentation and loss of habitat. This study examined the effect of land use on the species composition of frogs within North Eastern KwaZulu-Natal, and the use of buffer zones to facilitate the protection of these species. Three land use types were investigated: sugar cane (*Saccharum officinarum*), gum (*Eucalyptus* sp.) plantations and conservation areas. The average number of frog species differed between areas: conservation 13.2 ± 6.6; plantations 3.8 ± 1.3; and sugar cane 2.8 ± 1.4. Sugar and gum plantation were found to be lacking the wetland and grassland/woodland habitats. In addition to this, the frog species that were not present on these land use types were those that are totally dependent on water as well as those that are not dependent on a water source. Two species were highlighted as possible indicator species of land use: *Amietophrynus gutturalis* and *Hyperolius marmoratus*.

To mitigate the effect of these land use types, the use of buffer zones was explored in a desktop study. A range of buffer zones were applied to wetlands in a sample study area, using a range of distances including the distances of 290 m and 159 m recommended by Semlitsch and Bodie (2003), and the recommended distances for wetlands in South Africa of 10-20 m. The application of a 290 m and 159 m buffer zone on a conglomerate of wetlands connected by a 100m buffer was the most feasible as it incorporated a percentage of the total study (6.4% and 4.3%) area similar to the percentage occupied by the recommended 20m buffer zone (5.5%) around all wetlands, and still incorporated the range under protection put forward by Semlitsch and Bodie (2003). Management implications of these findings are discussed.

PREFACE

The data described in this dissertation were collected in the Republic of South Africa from November 2002 to May 2003, the desktop study was conducted from July 2006 till December 2010. Experimental work was carried out while registered at the School of Biological and Conservation Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Professor Colleen T. Downs.

This dissertation, submitted for the degree of Master of Science in the Faculty of Science and Agriculture, University of KwaZulu-Natal, Pietermaritzburg, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

…….

Charlene Russell

December 2010

I certify that the above statement is correct…

……..

Professor Colleen T. Downs

Supervisor

December 2010

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DECLARATION 1 - PLAGIARISM

I, Charlene Russell, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis.

Publication 1

C Russell and CT Downs. The effect of land use on the species composition of amphibians in North Eastern KwaZulu-Natal.

Author contributions:

CR conceived paper. CR collected and analysed data, and wrote the paper. CTD contributed valuable comments to the manuscript.

Publication 2

C Russell and CT Downs. The use of buffer zones within sugar and gum plantations to facilitate the conservation of amphibians in North Eastern KwaZulu-Natal.

Author contributions:

CR conceived paper. CR collected and analysed data, and wrote paper. CTD contributed valuable comments to the manuscript.

Signed: ……

Charlene Russell

December 2010

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Chapter 1

An overview of amphibian ecology

Introduction

The *Anura* of South Africa are numerous and widely distributed, however there is still much to discover about these vertebrates (Passmore & Carruthers 1979; Carruthers 2001; Channing 2001; du Preez & Carruthers 2009). Global declines in amphibians have alarmed scientists, indicating a possible worldwide ecological dilemma. This awareness has been brought about by the noted decline of populations and increased incidence of deformations found in amphibians (Alexander & Eischeid 2001; Beebee & Griffiths 2005; Griffiths et al. 2010). The suggested causes of these declines are global warming, increased ultra-violet radiation and pollution (Alexander & Eischeid 2001; Griffiths et al. 2010).

There has been an increase in awareness, worldwide of the biological importance of frogs (the word frog will be used but includes all *Anurans*) (Wake 1991; 1998). There is a wide diversity of species with a large degree of specialisation. They are found on all continents except Antarctica and there are as many species of amphibians as there are mammals and birds (Zug 1993). Frogs are vital entities in any food web, both as predators and prey (Beebee 1996). Populations are susceptible to environmental degradation due to their semi-permeable skins. The short lifecycle of the frog rapidly illustrates a decline in numbers when there is a change in environment (Alford & Richards 1999). For these reasons frogs can be used as early warning systems and bio-indicators of possible environmental defects (Wake 1991; Channing 1997; du Preez & Carruthers 2009). To understand how frogs could be used as indicators of the state of their environment, their general biology and biogeography must be examined. There are various environmental factors that limit the distributions of species, and may cause a reduction in the abundance of species (Mattison 1987). These variables will be explored in the literature review this document, with the intention of further understanding how frogs can be used as bio-indicators.

Global concerns have prompted scientists in South Africa to initiate the compilation of a Frog Atlas (Minter et al. 2000; Minter et al. 2004). The project started in 1995 and the resultant Frog Altas, published in 2004, has listed 23 red data species, 21% of the total number of *Anurans* (Branch & Harrison 2004, du Preez & Carruthers 2009). Frogs in South Africa are widely distributed and inhabit even the drier corners of the country. Most species, however, occur where human impact is high and as a consequence the main concern in South Africa is habitat loss (Channing 2001; Branch & Harrison 2004; du Preez & Carruthers 2009). Frogs play a vital role in ecosystem maintenance, and in particular, in wetland functioning (Beebee 1996). The importance of wetlands in South African ecology has received recent attention and funding. Wetlands are responsible for the filtering and stabilising of most of the country's water resources. In an area where water is nationally limited, and the driving force behind most ecological interactions, the protection of wetlands is essential (Hart & Allanson 1984; Kotze 1996). In South Africa, a buffer zone of 10m from the edge of a wetland is enforced (Conservation of Agricultural Resources Act 43 of 1983). This buffer zone protects the ecosystem functioning of the wetland but may not incorporate adequate natural vegetation to ensure the conservation of amphibian species (Semlitsch 1998). Semlitsch & Bodie (2003) recommend that a buffer zone with a range of 159m to 290 m, and that includes the natural habitat, is applied around wetlands to promote the conservation of amphibians.

Therefore the aim this study was is to explore the aspects of a frog's characteristics that make them susceptible to environmental change, the factors that affect their distribution, the possible causes of global declines, the use of frogs as bio-indicators, and the use of wetland buffer zones for amphibian conservation.

Study questions and objectives

This aim of this study is to provide answers for the following:

- To what extent does land use type (sugar cane, forestry and conservation) in northern KZN affect the composition of frog species?

- If so, what are the possible causes of this effect?
- What species can be used to indicate the state of the ecosystem?
- How can buffer zones be applied to facilitate the conservation of frog species?

Therefore this study has the following objectives:

- Determine if land use has had an impact on the species composition of anurans in the Zululand region of KwaZulu-Natal
- Determine if the species composition of anurans can be used as indicators of a decline in the quality of the environment they inhabit.
- Investigate how buffer zones can be used to facilitate the conservation of frog species.

Background information

General biology

There have been reports of amphibian declines worldwide (Wake 1991; Biek et al. 2002; Muths et al. 2003; Beebee & Griffiths 2005; Griffiths et al. 2010). Scientists have been alarmed by these findings, but are unable to agree if the phenomenon is due to natural population flux or genuine decreases in numbers. Experts are also unsure if these declines are a result of global changes in environment or to localised anthropogenic factors (Lips 1998 Biek et al. 2002; Muths et al. 2003; Beebee & Griffiths 2005; Griffiths et al. 2010). Before these issues can be resolved, the general biology and ecology of these vertebrates must be understood. Without comprehension of these aspects, population changes cannot be analysed. Further investigation in these areas will assist in the reliable use of frogs as environmental indicators.

Three aspects of amphibian biology increase their sensitivity to environmental degradation. These aspects are: a permeable skin; a complex life cycle; and a reliance of many species on individual water bodies for reproduction (Lips 1998). These factors shall be explored in further depth.

Anatomy

Frogs are vertebrates and share common characteristics with the animals in this group. To distinguish them from other vertebrates some aspects of their anatomy are unique. These aspects are the composition of their skin; a specialised auditory and visual system; and pedicellate teeth. These traits are common to all amphibians and indicate that they descend from a common ancestor and have subsequently adapted to suit their individual lifestyles (Townsend et al. 2003).

Calling behaviour plays a vital role in the reproductive strategies of frogs (Mattison 1987; du Preez & Carruthers 2009). An efficient auditory system is needed to support these strategies. The ears of a frog are paired structures found on opposite sides of the head and consist of an outer, middle and inner section. The outer ear is usually a slight depression covered with the tympanum. The middle ear consists of a double-channelled system, as opposed to the single channel that comprises the auditory system of most tetrapods. The additional channel, the opercular-amphibian papilla, enables frogs to detect low frequency sounds, those under 1000 Hz. These frequencies are produced by seismic vibrations from the ground and are detected by receptors on the limbs, which are then transferred to the inner ear and interpreted in the brain. This limb-opercular path is only found in frogs and salamanders. The sensory papillae of the inner ear are also specific to amphibians (Zug 1993; Channing 2001; du Preez & Carruthers 2009).

With regards to vision, frogs are also unique in that they are the only vertebrates able to raise and lower their eyes. They possess a muscle across the bony socket that contains the eye, which elevates the eyeball. The structure of the eyeball differs from other vertebrates, the layers of the retina are not found in the same sequence and the receptors face inward away from incoming light. Frogs are also the only animals to possess light receptors known as green rods, in addition to the usual red rods that detect colour. The function of these green rods is unknown (Duellman & Trueb 1986; du Preez & Carruthers 2009).

In contrast to the single solid structures that comprise the teeth of most vertebrates, frog's teeth consist of two separate sections: a pedicel, the elongated base set in the jaw bone; and the crown which protrudes above the gum. This two-part structure enables the frog to replace its teeth

as they wear down (Carruthers 2001; du Preez & Carruthers 2009). Each tooth is constricted at the base of the crown where it joins the pedicel, when the tooth is worn away to this constriction, it breaks off and is replaced by a new crown. Most frogs lack teeth on their lower jaw and a few lack teeth on the upper jaw. The reason for this is possibly to accommodate a projectile tongue, which is used to capture prey (Zug 1993).

The most defining aspect of a frog's anatomy is its skin. The composition of the skin and its function circumscribes the behaviour and life history of an individual. The semi-permeable nature of the skin limits its tolerance to its environment and dictates its dependence on water (Alford & Richards 1999). The skin serves multiple roles; it lends support and protection from the environment, it holds tissues and organs in place but must be flexible enough to permit movement and growth. It plays a role in sensory perception, osmotic control and thermoregulation (Townsend et al. 2003). In frogs more than in other vertebrates, the skin is a surface where respiration occurs. It is the exploitation of the skin as an organ of respiration that is the defining factor in the ecology of a frog. To permit respiration the surface of the skin must be kept moist. The frog possesses many unicellular mucous glands that produce a mucous coat that covers the epidermis (Zug 1993). The mucous keeps the surface moist for the process of gaseous exchange and contains antibiotics to prevent bacterial infections (Duellman & Trueb 1986). Frogs are also in the possession of granular glands that secrete a noxious solution. These granular glands are usually aggregated on the head and shoulders of an individual, which is the area first encountered by a predator. The same type of toxin is produced in all species but it varies in concentration, which ranges from mildly irritating to deadly. The skin of *Anurans* is loosely connected and is shed as the animal grows (Passmore & Carruthers 1979; Zug 1993; Duellman & Trueb 1986; Carruthers 2001).

The general anatomy of a frog is suited to its dual life in water and on land. It is this double existence that dictates the sensitivity of frogs to their environment (Beebee 1996). If either habitat is altered it could affect a large community. The most significant aspect of a frog's anatomy, with regard to its sensitivity, is its semi-permeable skin. In facilitating respiration, the skin is reliant on moisture and susceptible to chemicals. These two factors limit the frog's resilience to

environmental change and designate it a worthy bio-indicator (Poynton & Boycott 1996; Hartwell & Ollivier 1998; Beebee & Griffiths 2005; Griffiths et al. 2010).

Life History

The life history of an individual includes every aspect of its life from conception to death (Wilson 1992). Life history refers to the key traits exhibited by the general population. These key traits are: life span; age at sexual maturity; fecundity; and annual reproductive effort (Mattison 1987; Wilson 1992). The differences in these traits denote the alternative strategies employed by each species, which ensure their evolutionary success. The different strategies further denote how susceptible a species is to environmental change. By examining the general life history patterns of frogs it can be better understood why they are good indicators of ecosystem stress (Hartwell & Ollivier 1998; Wilson 1992; Zug 1993).

Most species of animals can be divided into two groups with contrasting life history states, generally referred to as r and K-strategies (Wilson 1992). Those species that employ an r-strategy have short-lived populations; early sexual maturity; large broods and high annual reproductive effort. The opposing K-strategy exhibits long-lived populations; delayed sexual maturity; small broods and low annual reproductive effort (Wilson 1992; Townsend et al. 2003). The ancestors of frogs employed a general r-strategy. They relied on aquatic breeding, producing numerous offspring in a single clutch (semelparity) or in many clutches throughout the breeding season (iteroparity). They had a short lifespan and a high mortality in all age classes. These life history states are still exhibited by small *Anurans* in seasonal environments (Zug 1993).

Modern *Anurans* that don't display this general life history strategy have diverged into two groups (Zug 1993). The first are still reliant on aquatic breeding but have increased their lifespan and their body size. With a larger body, they are able to produce larger clutches and have a higher lifetime reproductive effort. Examples of *Anurans* in this group are large bodied bufonids and ranids (Bass 1966; Passmore & Carruthers 1979; Mattison 1987; du Preez & Carruthers 2009). The other

group have reduced or completely eliminated aquatic breeding. They employ parental care and extra-uterine ovoviviparity (eggs develop within the parents body, seemingly giving „birth' to fully developed young). Some species of this group develop directly and skip the tadpole phase. Most examples of these species are forest dwellers in tropical regions (Zug 1993).

Environmental perturbations are usually evident at the population level, where a decrease in numbers occurs (Wilson 1989; Biek et al. 2002). This would occur first in the populations with the fastest turnover of generations. In aquatic environments these populations are usually the invertebrates. A decrease in numbers of invertebrates is sometimes not easy to detect and is usually only visible when it affects animals higher in the food chain, like amphibians. Frogs have a relatively short life span when compared to other vertebrates. A change in environmental conditions that prevents successful reproduction will cause a visible change in population numbers. Frogs have a dual life history and are reliant on habitats both in the water and on land, and are sensitive to changes in both strata (Bass 1966; Vitt et al. 1990; Wake 1991; and Blaustein et al. 1994).

Most species of *Anurans* rely on water for reproduction. Often a single water source will support many individuals of various species. Each species uses the water source in a different and unique manner. If some mishap were to befall that area, many species would be prevented from breeding (Lips 1998). This would be illustrated by a decrease in population numbers the following season. If the area does not recuperate the effect would accumulate and have more serious repercussions. Tadpoles are highly adapted to suit the strata that they inhabit in a water source. Minor environmental changes can destroy entire cohorts (Hartwell & Ollivier 1998). The life history variables of frogs: their duality, specialisation, and short-lived populations add to their suitability for use as environmental indicators.

In South Africa the life histories of *Anurans* are diverse (Passmore & Carruthers 1979; du Preez & Carruthers 2009). Populations that inhabit the same area are able to co-exist without being in direct competition for the available resources. The reason this is possible is because they employ different strategies and utilise alternative niches. The common guttural toad

(*Amietophrynus gutturalus*), for example, is an opportunist. It feeds on what is available and reproduces whenever the conditions are favourable (Channing 2001). Other species only breed once a year, after the first rains of spring. Some only at the end of summer when the water levels have reached the maximum. *Xenopus laevis*, the common platanna, is a species that is completely aquatic from the larval stage through to adulthood. The Bushveld Rain Frog (*Breviceps adspersus*) is a species not reliant on open water bodies at any stage of its development. To attract a mate the male calls while walking around on the surface or from within a deep burrow in open or lightly wooded savanna. The tadpoles are laid and develop in a muddy nest within the burrow (Carruthers 2001; du Preez and Carruthers 2009). The wide diversity of life histories in South Africa is mainly due to the wide variety of available habitats. This variation in habitat type has facilitated the development of many species and is the reason South Africa can boast an impressive diversity of *Anurans* (Channing 2001; du Preez and Carruthers 2009).

Role in Ecology

Ecology is the study of ecosystems and how the communities they support interact and function together (Townsend et al. 2003). Exploring how frogs reside in these communities will give a better understanding of the manner in which they can be used to as indicators of the status of their ecosystem (Hartwell & Ollivier 1998). Each organism has a role to play as a provider and consumer in a delicately balanced arrangement of finite resources. Every species is theoretically as important as the next. Frogs play the role of both predator and prey in any system they inhabit (Dodd & Cade 1998). They are widely spread across the globe and occupy almost every conceivable habitat type. A species of toad is even found in the Artic, the presence of an “anti-freeze” in its blood allows it to survive the harsh winters (Beebee 1996).

The dual life style of frogs allows them to occupy different niches during their development. As tadpoles, most species are herbivorous, and generally microphagous, feeding on algal and bacterial scum that covers all objects immersed in water. Few tadpoles deviate from this (Beebee 1996). The larvae of *Pyxicephalus adspersus* are an exception, as they tend toward carnivorous

behaviour and have been known to prey on other tadpoles (Carruthers 2001; Channing 2001). As adults, all frogs are carnivores and unable to process plant matter. They are predators who will prey on anything smaller than themselves, including other amphibians. Their diet ranges from the smallest arthropods to birds and small mammals (Passmore & Carruthers 1979; Zug 1993; Carruthers 2001; Channing 2001).

To avoid capture by a predator, a frog can rely on a number of defensive strategies. An individual's primary concern is to avoid detection (Mattison 1987). Avoiding the search path of a predator is the most obvious tactic. This can be done by having an alternate activity cycle or inhabiting a different region to that of a predator. Most frogs limit their exposure to predators by being nocturnal (Carruthers 2001; du Preez & Carruthers 2009). There are also many species that implement camouflage as an approach to avoid detection. Early identification of a predator is also important, this ensures that an escape can be made. Tadpoles release an „alarm' substance in the presence of a predator, which alerts all the tadpoles in the immediate vicinity. The co-operation of tadpoles within a group provides protection for the individual (Zug 1993).

If a predator cannot be avoided, then the individual employs its second level of defence, that of crypsis and confusion (Zug 1993). Many species of frogs seem brightly coloured and patterned when taken out of their natural habitats, but blend in to their normal environments. The Tinker Reed frog (*Hyperolius tuberilingus*) is such an example, its colour is near luminous green or yellow but within the wetland vegetation it inhabits it is almost impossible to distinguish (Bass 1966; Passmore & Carruthers 1979; Channing 2001). Most species of toads also use camouflage with their brown mottled appearance softening their outlines (Carruthers 2001). Toads and other frogs make use of a defensive posture to add to their camouflage. When detected by a predator they often flatten themselves against the ground. This posture eliminates the edge effect of the animal and disrupts the predators search image (Zug 1993).

Factors affecting distribution

Local distribution

The factors governing the distribution of a species are important to examine as they lead to a greater understanding of the causes of species declines (Alford & Richards 1999; Griffiths et al. 2010). The distribution of a species is governed by changing factors. These factors define where a species is found on two levels; the distribution of the population, and of the individual (Zug 1993). A population is comprised of a group of organisms of the same species, which inhabit a region that enables them to interact and breed (Townsend et al. 2003). The scope of a population is regulated by the physiological tolerances of the species and availability of resources. The range inhabited by an individual is defined by intraspecific competition for common resources such as space, food, water, and mates. Local distribution is the spacing of individuals amongst members of the same species (Zug 1993).

The factors that affect local distribution are the factors that define the size of a species home range (Zug 1993). The home range is the area occupied by an organism on a daily basis that allows it to perform its usual activities (Townsend et al. 2003). The size and locality of an individual's home range may vary between seasons and populations (Dodd & Cade 1998). The home range of an amphibian is measured on a three dimensional scale (Bass 1966). Most amphibians are sedentary and occupy an area of about $10m^2$ to $1000m^2$ for the majority of their life span (Zug 1993; Semlitsch 1998). Some species may inhabit completely different regions at adulthood compared to the larval stages, or during breeding periods (Semlitsch 1998; Carruthers 2001; Channing 2001; Semlitsch & Bodie 2003). The life history of a species, thus, plays a role in determining the locality of its home range.

The size of an organism's home range is a direct function between the availability of resources and the energy required to collect the resources needed for maintenance, growth, and reproduction (Semlitsch 1998). The energy used in foraging for food must not exceed the energy gained from the food that is collected, or place the individual at any extreme risk of predation (Welsh & Ollivier 1998; Townsend et al 2003). The availability of resources depends on the

number of individuals competing for their consumption, both interspecifically and intraspecifically. The greater the number of individuals of the same species, the greater the competition for food, water, space and mates (Townsend et al. 2003). The input of energy into obtaining these resources by the individual, under these circumstances, will have to be increased, leaving less energy for physiological functioning. A dynamic equilibrium is therefore reached between the amount of available resources and the number of individuals competing for them. This number of individuals determines the size of each home range (Zug 1993).

The size, locality and degree of overlap between each home range of an individual member of a species contributes to the distribution of the species as a population. The factors that affect the availability of resources for the individual also affect the range of that population. Local distribution, intraspecific competition and the availability of resources affect the distribution of the population as a whole. Populational distribution is also affected by biogeographical factors such as historical dispersal, species physical tolerances and climate (Semlitsch 1998; Carey et al. 2001).

Populational distribution

The area that a population inhabits is limited by the availability of the resources needed for the continuance of the species (Werner et al. 2007). Certain individuals may be found outside of the populational boundaries but the conditions at that site may not facilitate breeding or the subsequent survival of further generations of that species (Vallan 2000). The boundaries of a population are in a constant flux between survival and extinction (Zug 1993). Historical events have affected the dispersal and speciation of a population and give some explanation of the current distribution (Cushman 2006; Werner et al. 2007). It is necessary to examine the origin and evolution of amphibians to fully understand their distribution today (Zug 1993).

Scientists believe that approximately 400 million years ago fresh water lobed- fin fishes, *Rhipidistian crossopterygians,* developed short robust fins (Carruthers 2001; du Preez & Carruthers 2009). These fins served as props and allowed the organism to walk along the bottom,

with the body of the fish suspended in the water. These structures gradually adapted to environments with less water and became more sturdy and flexible. Lungs developed early in Bony fishes, most likely due to anoxic or low-oxygen conditions within water bodies. These developments facilitated the progression of organisms from an aquatic environment to a terrestrial one. Fossils of a semi-aquatic organism have been discovered, named *Icthyostega*, which was able to move between water bodies in times of drought. This organism is one of the first tetrapods and it is likely that the ancestors of amphibians were structurally similar to *Icthyostega*. *Tetrapoda* diverged into two lineages, one that gave rise to modern day reptiles and the other to amphibians. Many primitive forms of amphibia went extinct but the group *Lissamphibia* developed into the present forms of amphibians that are found today: Caecilians, Salamanders, and Frogs (Fig 1.1). *Lissamphibia* occurred in the Mid-Permian Period and the distribution of these three groups coincides with the separation of the landmass into Gondwanaland and Laurasia. Fossils of the five groups of Salamanders are found only in the Northern Hemisphere; and evidence of the first frogs and caecilians is confined to the Southern Hemisphere (Zug 1993).

Frogs (*Salientia*) are divided into two major groups: *Proanurans* and *Anurans*. *Proanurans* are the earliest and structurally most primitive frogs, of which, all species are now extinct. These early frogs are of Gondwanan origin, and appear to have arisen and radiated from the southern continents (Zug 1993; Carruthers 2001; du Preez & Carruthers 2009). The first fossil frog, *Triadobatrachus,* was dated to the early Triassic Period and was found on Madagascar (Glaw & Vences, 1992). This is the only known example of a *Proanuran.* Subsequent groups of frogs, the *Anurans*, are divided into three groups: *Archaeobatrachians,* the most primitive families; *Mesobatrachians*, transitional frogs; and *Neobatrachians*, modern frogs (Zug 1993).

Most of these families originated in the Southern Hemisphere and fossil remains track their radiation northwards, however, some *Neobatrachians* have histories confined to the northern hemisphere and their radiations are similar to salamanders (Zug 1993; Beebe 1996). The family *Pipidae* (Table 1.1) are one of the most primitive families still in existence. The first fossil records of this *Mesobatrachian* family appear during the early Cretaceous period. Three genera from this

period were found in the Mediterranean, which suggests an early radiation of the African pipids. The most adaptable and diverse of this group is the genus *Xenopus*. Fossils have been found in Nigeria from the late Cretaceous and in Libya from the Oligocene. Two species were found in

mainly across the tropical regions worldwide. Hyperolidae are only found on the African continent and on Madagascar, this family includes the genera *Afrixalus, Kassina, Semnodactylus, Hyperolius* and *Leptopelis*. *Chiromantis* belongs within the family Rhacophoridae, which are the tree frogs of Africa, Asia and Madagascar (Passmore & Carruthers 1979; Zug 1993; Carruthers 2001; Channing 2001). Ranidae Brazil and Argentina, but have subsequently gone extinct (Zug 1993). Of the other southern African frog families, Bufonids are found worldwide (Table 1.1), but are polyphyletic, arising from differing origins. The family Heleophrynidae are endemic to South Africa, are only found in clear swift, vegetated mountain streams, kloofs, forests and grassland. The Genera *Breviceps* and *Phyrnomantis* belong to the family Microhylidae, which are intermittently distributed, which are known as true frogs (Carruthers 2001), are found worldwide and is a highly speciose family which includes the following Southern African genera: *Amietia, Hildebrantia, Hylarana, Ptychadena, Pyxicephalus, Strongylopus, Tomopterna, Anhydrophyrne, Arthroleptella, Phrynobatrachus* and *Poyntonia*. Zug (1993) includes *Arthroleptidae* and *Hemisotidae* within the family Ranidae, but Carruthers (2001) lists them as separate families of their own.

Current distributions of frogs can be explained by the biogeographical theories of vicariance or dispersal (Townsend et al. 2003). Dispersal places a population with a centre point of origin from which each group moves outwards and across barriers (Werner et al. 2007). The resultant communities are formed from one or several centres. The theory of vicariance states that populations are stationary and have been divided by geographical events that produce barriers. Groups are subsequently isolated and evolve separately. Vicariance is generally the preferred explanation, but this may be because it is easier to test. In most regions the histories of the communities are so complex that both concepts can be used to explain the distribution of populations (Zug 1993).

The South African distribution of *Hyperolius nasutus* (Long Reed Frog) is widely separated from the northern population (Carruthers 2001; Channing 2001; du Preez & Carruthers 2009). This phenomenon could have occurred as a vacariance event, where a barrier developed dividing the northern and southern populations. If a smaller group of the original population spread southwards until they reached their current destination, then this pattern of distribution could be explained by dispersal. Deciding how a population came to inhabit the area it does can be done by examining geographic history, discovering the time that a barrier such as a desert or mountain range came into existence, and comparing it to the age of fossil remains (Zug 1993).

Every organism is only able to tolerate certain conditions. Climate is a variable factor that defines the range of most animals. In South Africa 53% of the total number of species are found within the northeastern section of the country (Fig 1.2). This area of the country has the highest rainfall and the warmest average temperatures, which makes this area the most suitable for amphibian inhabitation. Bass (1966) describes a noted subtraction of tropical frog species from the north and appearance of non-tropical species in the south, around the Greater St Lucia Wetlands Park area on the northeastern coast of KwaZulu-Natal. Temperature appears to be the explanatory factor for this phenomenon, as the subtraction of tropical species coincides with the 18°C July isotherm (Poynton 1964). This can also be seen in the distribution of species recorded in the Frog Atlas and Red Data Book (Minter et.al. 2004).

The majority of amphibians are limited to specific areas because of their reliance on water due to their semi-permeable skin (Mattison 1987). There are a few species that inhabit drier areas and have adapted to harsher conditions. By occupying a niche in a harsh environment a species can avoid competition. The Desert Rain Frog (*Breviceps macrops*) is found on desert and coastal sand dunes in the Namib Desert (Carruthers 2001; du Preez & Carruthers 2009). The rainfall in this region is below 400mm per annum. In South Africa frogs can be broadly divided into three groups depending on their reliance on bodies of water (Passmore and Carruthers 1979). Species such as *Xenopus laevis* are totally aquatic and spend most of their life in water (Measey 2004). Rain Frogs (*Breviceps sp.*) occupy the opposite end of the scale and do not rely on water bodies at

any stage of their life history, even for breeding (Minter 2004). Intermediate species are those that use water bodies for breeding, but generally occupy other areas, like Grass Frogs (*Ptychadena sp.*) (Channing 2004).

Climate, species tolerance levels and competition for resources determine the distribution of a population. Within a region not all species inhabit the same niche (Bass 1966). Distribution occurs on a three dimensional level, and populations that are found within the same area may not occupy the same space, or rely on the same resources. An environmental disturbance within an area may not, therefore, affect all the species that occupy that region. A change in range of a single population indicates that something is amiss within that ecosystem, which is why it is important to understand the distribution patterns of frogs and how they can be used to signal environmental change.

Amphibian declines

Research in the 1980's alerted scientists to the possibility that certain amphibian species were less abundant or becoming extinct. What was most alarming about these findings was that the declines were occurring in relatively undisturbed regions and even in areas under conservation (Corn and Fogleman 1984; Heyer et al. 1988; Weygoldt 1989; Lips 1998 Biek et al. 2002; Muths et al. 2003; Beebee & Griffiths 2005; Griffiths et al. 2010). Global concerns about amphibian declines were initially brought to light at the First World Congress of Herpetology in 1989 (Barinaga 1990; Wake 1991). Since then scientists have had to resolve certain issues surrounding the documented cases of declines. It is not clear yet if these decreases in abundance are a normal fluctuation in population numbers, if they are isolated instances, or a problem occurring on a global level (Lips 1998). The most noted declines have been recorded in North and South America, Puerto Rico, Costa Rica and Australia (Pounds and Crump 1994; Alford & Richards 1999; Alexander & Eischeid 2001; Carey et al. 2001). Most cases have acknowledged a reduction in frog species that inhabit high elevation streams (Bradford 1991; Carey 1993; Lips 1998; Pounds et al. 1999; Alexander & Eischeid 2001). The disappearance of amphibians could signal the beginning of a global extinction

of species. Anthropomorphic effects have caused changes in the environment, climate and the atmosphere. The extent of the effect that these changes have had on ecosystems and how they function has not yet been measured effectively. Scientists are treating the decline in amphibian numbers as an early warning of more catastrophic events to come. Identifying the causes of these declines will give a greater understanding of how to mitigate the effects (Houlahan et al. 2000).

Climate limits the distribution of frog species, which is why changes in climate have been investigated as a cause of declines of species within a region (Beebee 1995; Fisher & Shaffer 1996; Parmesan 1996; Lips 1998; Beebee & Griffiths 2005; Griffiths et al. 2010). Global warming and the subsequent effects on climate have become an issue worth examining (Intergovernmental Panel on Climate Change 1996). Abnormally dry conditions, frequent summer droughts, excessive rainfall in cooler months and increased summer temperatures have all been proposed as causes of amphibian declines (Osbourn 1989; Weygoldt 1989; Ingram 1990; Fellers & Drost 1993; Pounds and Crump 1994; Laurance 1996). Alexander and Eischeid (2001) examined climate data and amphibian population changes on a macro-level, using a re-analysis system and area-averaged station data. Their results did not show a significant correspondence between temperature fluctuation and species declines. They concluded that unusual climate factors, such as decreased precipitation and increases in temperature, are unlikely to be the direct cause of amphibian declines. They suggest that climate may be an indirect cause, by facilitating the propagation of certain pathogens that cause amphibian mortality. The results of an investigation into the decline of amphibians in Puerto Rico by Stallard (2001), also illustrates a similar relationship between climate change and population numbers. He states that changes in climate are not extreme enough to be the direct cause of declines within that region. Large scale, long-term data indicates that climate may affect related environmental variables within a system and affect synergistic interactions, which contributes to species declines (Carey et al. 2001).

In conjunction to climate change, ozone thinning has been highlighted as a possible cause of global amphibian declines (Alford & Richards 1999). The thinning of the ozone has increased the amount of ultraviolet radiation that reaches the earths' surface (Stolarski et al 1986; McKenzie

et al. 1999). Several studies have been conducted to quantify the effect of UV on amphibians. Some investigations have concluded that UV-B radiation has a negative effect on the survival of amphibian embryos and larvae (Long et al. 1995; Anzalone et al. 1998). Formicki et al. (2003) stated that increased UV-B caused significant decreases in oxygen consumption in *Bufo bufo* tadpoles. Ultraviolet B radiation was also found to have significant negative effects on the growth and development of *Rana temporaria* (Pahkala et al. 2003). Frog species have differing levels of photolyase, the enzyme responsible for the repair of ultraviolet B (UV-B) radiation damage (Blaustein et al. 1996). The impact of UV-B differs between species, some species are more sensitive to UV radiation than others (Corn 1998). Some studies have shown no significant effects of increased UV radiation (Blaustein et al. 1996; Corn 1998; Blaustein et al. 1999). The species most affected by an increase in UV radiation appear to be those that breed in clear, shallow water, at high elevations (Blumthaler & Ambach 1990; Anzalone et al. 1998; Lizana & Pedraza 1998). The effects of UV radiation, however, have not been proven to be a direct cause of amphibian declines (Middleton et al. 2001). When found in addition to other factors, they have certain indirect effects that could contribute to the global phenomenon. Ultraviolet radiation increases could cause a change in water chemistry, affect the food supply of amphibians, and cause physiological damage to species, which decreases an individual's evolutionary success (Alford & Richards 1999).

Besides the effects of climate change, global warming and increased UV radiation on amphibians there are various other factors that could contribute to declines. These factors are: change in acidity and toxicants; pathogens; introduced exotic species and habitat modification (Alford & Richards 1999; Griffiths 2010). The sensitivity of frogs to their environment has already been explored in this document, it follows that to examine the extent to which toxicants and changes in pH have had on declines in population numbers. Low pH levels in aquatic habitats have been shown to negatively affect the distribution, reproduction and survival of eggs and larvae of frog species (Wyman 1990). The chemicals used in pesticides affect the growth and development of tadpoles (Channing 1997).

The increased instance of pathogens in amphibian habitats has led to several reports that have suggested that disease has played a role in global declines (Beebee 1977; Bradford 1991; Wake 1991; Carey 1993; Muths et al. 2003). The fungus *Saprolegnia ferax* has been identified as the pathogen responsible in most cases of embryonic mortality in amphibians (Blaustein et al. 1994). Those species that lay their eggs in a large communal mass are most at risk to the effects of *S. ferax*, as the fungus is easily passed from one egg to another (Kiesecker et al. 2001). The negative effects of this pathogen, autonomously, may not be severe enough to account for any significant declines, but when coupled with the effects of UV radiation the frequency of mortalities increase (Kiesecker et al. 2001). Mortalities in amphibians caused by *S. ferax* are greater when rainbow trout have been introduced into the system. The introduced species are carriers of the pathogen, and even soil from fish farms has been found to contain the fungus (Kiesecker et al. 2001). Introduced species cause imbalances within an ecosystem in terms of upsetting predator-prey ratios, but they can also bring in other exotic parasites and pathogens (Muths et al. 2003). In recent years much attention has been given to the extent and effects of the chytrid fungus *Batrachochytrium dendrobatids* on local population declines in frog species (McCallum 2004). The fungus has caused local extinctions in areas across Australia and Central America (Berger et.al. 1998; McCllum 2004; Schloegel 2006). The distribution and full effect of this fungus is currently being researched and is considered as a phenomenon that has been underreported (Schloegel 2006).

Probably the largest impact humans have had on their environment is that of habitat modification and destruction. The removal of habitat types has displaced many species, and caused many to become endangered. Amphibians have not been excluded from this effect. Many amphibian species breed only within specific habitat types, and are unable to successfully reproduce if that habitat type has be removed (Mattison 1987). Habitat destruction is the most wide spread factor contributing to global amphibian loss (Alford & Richards 1999; Blaustein & Kieseker 2002; Behangana & Arusi 2004; Griffiths et al. 2010). The effects of habitat loss and fragmentation are discussed in greater depth in the following section.

On examination of the literature available, it appears that scientists have been unable to locate a direct cause of global amphibian declines. The factors such as climate change, increased UV radiation, acidity, toxicants, pathogens, exotic species and habitat modification have all been shown to have a negative, but indirect, effect on amphibian populations. These factors independently may not be responsible the global phenomenon, but combinations of some or all the factors could facilitate the decrease in amphibian numbers (Alford & Richards 1999). The hole in ozone layer, increases the amount of UV-B radiation, which could cause a change in local climate, the increase in UV-B perpetuates the production of the *S. ferax* fungus (Kiesecker et al. 2001), which decreases the number of individuals in a population. If this occurs within an area that has been impacted by humans; where pesticides and fertilizers have polluted the water bodies; and large-scale habitat destruction has taken place; then the survival of the entire amphibian population within that area is at risk. Each area where declines have been noted needs to be treated individually, as the combinations of the factors may differ. This presents a new and unique dilemma at every site. Amphibian declines are a global problem that requires local solutions.

Habitat loss and Fragmentation

Human population has increased substantially over the last 100 years. Demand for space for human settlement, agricultural production and industry has placed natural areas under threat. Habitat loss and fragmentation has threatened species diversity and richness (Fahrig & Merriam 1994; Vitousek et al. 1997; Fahrig 1998; Fahrig 2001; Pineda & Halffter 2004; Beebee & Griffiths 2005; Griffiths et al. 2010). Removal of suitable habitat is one of the main contributing factors to global amphibian declines (Alford & Richards 1999; Blaustein & Kieseker 2002; Behangana & Arusi 2004; Griffiths 2010). The effects of habitat removal on amphibians have been studied in relative depth, but at various scales, from site-specific studies to broad landscape investigations (Vallan 2000; Carr & Fahrig 2001; Houlahan & Findlay 2003; Bowne & Bowers 2004; Cushman 2006). The terms „habitat loss' and „habitat fragmentation' are extensively used, sometimes interchangeably, and may need to be more clearly defined (Edenhamn et al. 1992). Habitat loss

implies the removal of habitat, to such an extent that the remaining areas of suitable vegetation and optimal conditions are too small to support a viable population (Fig 1.3). Fragmentation is the disintegration of habitat, resulting in smaller portions of suitable regions separated by areas of incompatible space (Fig 1.3) (Wilcove et al. 1986). Both of these phenomena have consequences for amphibian populations.

The loss of habitat for frogs reduces their distribution (Cushman 2006). Frogs are sensitive to their environment and can't exist where the conditions are not suitable. Habitat fragmentation does not necessarily exclude amphibians from an area, but it may reduce species richness and diversity (Behangana & Arusi 2004). Certain species are more sensitive to fragmentation than others (Alford & Richards 1999; Vallan 2000; Behangana & Arusi 2004; Cushman 2006). Fragmentation may result in a loss of species from certain groups, reducing biodiversity and possibly affecting ecosystem functioning (Pearman 1997; Knutson et al. 1999; Bell & Donnelly 2006). Each species has its own optimal range of conditions under which it can survive, and can tolerate a reduction of suitable habitat within certain limits. Perhaps the question to ask is when does habitat fragmentation become habitat loss? The answer to this is dependent on landscape variables such as connectivity, distance between habitats, size of fragments, and landscape heterogeneity (Vallan 2000; Pineda & Halffter 2004; Bell & Donnelly 2006).

The effects of habitat fragmentation have mostly been examined at a local level (Cushman 2006). To fully understand the populational implications, the focus of research has to move from site-specific connotations to larger scale studies that encompass a multitude of effects on the total population across a landscape (Carr et al. 2002; McGarigal & Cushman 2002; Bowne & Bowers 2004). This invokes the use of metapopulation theory. The basis of this theory employs a landscape that is divided in to patches, where the occupation of each patch is defined by extinction and colonisation rates. Isolated patches and small populations are the most vulnerable to extinction because of their intrinsically low rate of re-colonisation (Levins 1969; Vallan 2000; Werner et al. 2007). The paradigm opposing the metapopulation theory is the habitat paradigm. This states that occupation of an area is solely defined by the habitat variable needed by the

species. If the quality of the habitat decreases within an area, then the possibility of species extinction increases (Manel et al. 1999; Guisan & Zimmermann 2000; Armstrong 2005; Bell & Donnelly 2006). Armstrong (2005) suggests that an integration of these two paradigms is possible, and will benefit the understanding of broad-scale species declines. Both paradigms have consequences for habitat fragmentation and implications for issues of connectivity.

Issues of connectivity between suitable habitats

A fragmented habitat is a diverse landscape. How fragments are connected to each other has implications on how a species might be distributed (Reh & Seitz 1990). The distance between fragments is important to consider (Brown & Kodric-Brown 1977). If fragments are too widely separted a population may not be able to move between them (Pope et al. 2000). The type of space between fragments must also be considered (Fahrig & Merriam 1994). Vegetation might promote easier movement between fragments than a hostile space such as a road (Vos & Chardon 1998; Carr & Fahrig 2001). Even if the distance between fragments is not great, if the space between them is inhospitable, dispersal might not take place (Gibbs 1998; de Maynadier & Hunter 2000; Bell & Donnelly 2006). The space surrounding a fragment can add to its isolation. Certain features can connect fragments. Artificial ditches may connect wetlands or ponds. These ditches may not be the optimal habitat type for frogs, but are a more favourable environment and do allow movement between breeding sites (Reh & Seitz 1990).

The use of buffer zones

Habitat for amphibians needs to be regarded as a complex feature (Pope et al. 2000). Conservation for amphibians has been focused on conservation of breeding sites (Zimmermann & Bierregaard 1986; Semlitsch 1998; Semlitsch & Bodie 1998). Many species require a varied landscape to support all aspects of their life history (Gill 1978; Wilbur 1980; Pope et al. 2000). Some may require a pond or wetland for breeding, but use the surrounding grassland for feeding,

protection or burrowing. This must be considered when assessing the effects of habitat fragmentation. A breeding site may still remain intact, but if there is no suitable habitat surrounding it, the species may be excluded from the area (Reh & Seitz 1990; Pope et al. 2000). Thus, the habitat is lost. The value of wetlands within agricultural areas has been recognised (Lowrance et al. 1984). Great lengths have been taken to preserve the functioning of these ecosystems, but most of the emphasis has been on protecting the soil and water processes (Burke & Gibbons 1995). Most commercial agricultural practices enforce the use of buffer ones around wetland to preserve them. These buffer zones protect the functioning of the wetland but not necessarily the species that rely on them. Within many agricultural and forestry zones amphibians are excluded from these wetlands because the surrounding habitat does not support them (Semlitsch & Bodie 1998; Semlitsch & Bodie 2003). Buffer zones are a management tool that has been used to mitigate the effects of habitat fragmentation but if they are not correctly instigated no benefits to biodiversity will be seen (Semlitsch & Jensen 2001).

Frogs as bio-indicators

A bio-indicator is a species that is sensitive to changes within its environment. Those species that initially show a decrease in numbers following an environmental disturbance are likely candidates for the use as indicators of the „health' of a system (Odum 1992). A good indicator is a species that is abundant; easily identifiable; sensitive to ecosystem stress; whose natural variation in numbers can be distinguished from those caused by ecosystem dysfunction (Rapport 1992; Welsh & Ollivier 1998). Indicator species can be an invaluable tool in detecting when a system is in trouble. Early detection can allow ecologists to prevent further damage. Comprehensive and systematic use of biological indicators can facilitate the monitoring of an ecosystem (Rapport 1992, Du Preez and Carruthers 2009).

Most species of frogs have a dual life history; they are reliant on both terrestrial and aquatic habitats. They have specific microhabitat requirements. Their semi-permeable skin makes them vulnerable to chemicals and heavy metals. These factors lend to their suitability for use as

indicators of ecosystem stress (Vitt et al. 1990; Wake 1991; Blaustein 1994; Blaustein et al. 1994; Stebbins & Cohen 1995). Frog Embryo Teratogenesis Assay – *Xenopus* (FETAX) was developed in the 1980's to establish the presence of pollutants within aquatic systems. This toxicity test is conducted on the embryos of *Xenopus laevis* (Bantle et al. 1989) and quantifies the level of toxicant by the malformation and mortality of the embryo at 96 days. This species is widely distributed throughout South Africa. Channing (1997) has identified FETAX to be feasible method to test the levels of chemicals from pesticides within South African rivers. A modified method based on FETAX has been used in South Africa to assess the levels of heavy metal pollution from gold mining. It used both embryos and tadpoles and was found to be successful in quantifying the severity of Zn, Cu, Pb and Cd pollutants (Haywood et al. 2004). Tadpoles from other species have also shown similar reactions to the chemicals found in pesticides, herbicides and fertilizers (; Bidwell and Gorrie 1995; Semlitsch et al. 1995).

Welsh and Ollivier (1998) approached the use of amphibians as bio-indicators at a community level. They compared species density at streams affected by human activity to streams with no impact. It was concluded that the density of amphibians was significantly different enough to be used as an indication of ecosystem stress. Amphibians occur in relatively stable populations, they are abundant and long-lived, habitat specific, and can be recognised quickly through the identification of their calls (Behangana 2004). These features make them more reliable indicators than macroinvertebrates and anadromous fish (Welsh & Ollivier 1998). Macroinvertebrates and fish can give an indication of water quality, but because frogs rely on both terrestrial and aquatic habitats, they give a more holistic indication of ecosystem functioning (Behangana 2004).

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Table 1.1: Classification and Distribution of Extant Frogs (adapted from Zug 1993).

Classification	Distribution
Amphibia	
Lissamphibia	
Salientia	
Proanura	
Anura	
• Archaeobatrachia	
Family Ascaphidae (1 species, tailed frog)	North America
Family Discoglossidae (3 species)	Europe and Asia
Family Leiopelmatidae (14 species, small frogs)	New Zealand
• Mesobatrachia	
Pipoidea	
Family Pipidae (25+ species, clawed frogs)	Africa and South America
Family Rhinophrynidae (1 species, toad-like)	Central America
Pelobatoidea	
Family Pelobatidae	North America, Europe, Himalayas, SE Asia
Family Pelodytidae	Europe and Asia
• Neobatrachia	
Bufonoidea	
Family Brachycephalidae	South Eastern Brazil
Family Bufonidae (true toads)	All continents (introduced to Australia by man)
Family Centrolenidae (glass frogs)	American tropics
Family Dendrobatidae (poison arrow frogs)	Neotropical forests of Central and Southern America
Family Heleophrynidae (ghost frogs)	South African mountain streams
Family Hylidae (tree frogs)	Northern Hemisphere
Family Leptodactylidae	Neotropics
Family Myobatrachidae (toad-like)	Australia
Family Pelodryadidae (tree frogs)	Australia and New Guinea
Family Pseudidae	Argentina
Family Rhinodermatidae	South American eastern temperate forests
Family Sooglossidae	Seychelles
Microhyloidae	
Family Microhylidae (rain frogs and rubber frogs)	Tropics worldwide, distribution discontinuous
Ranoidea	
Family Hyperolidae (reed frogs and tree frogs)	Africa and Madagascar
Family Ranidae (true frogs, river and stream frogs)	Worldwide
Family Rhacophoridae (tree frogs, foam nest frogs)	Africa, Madagascar and Asia

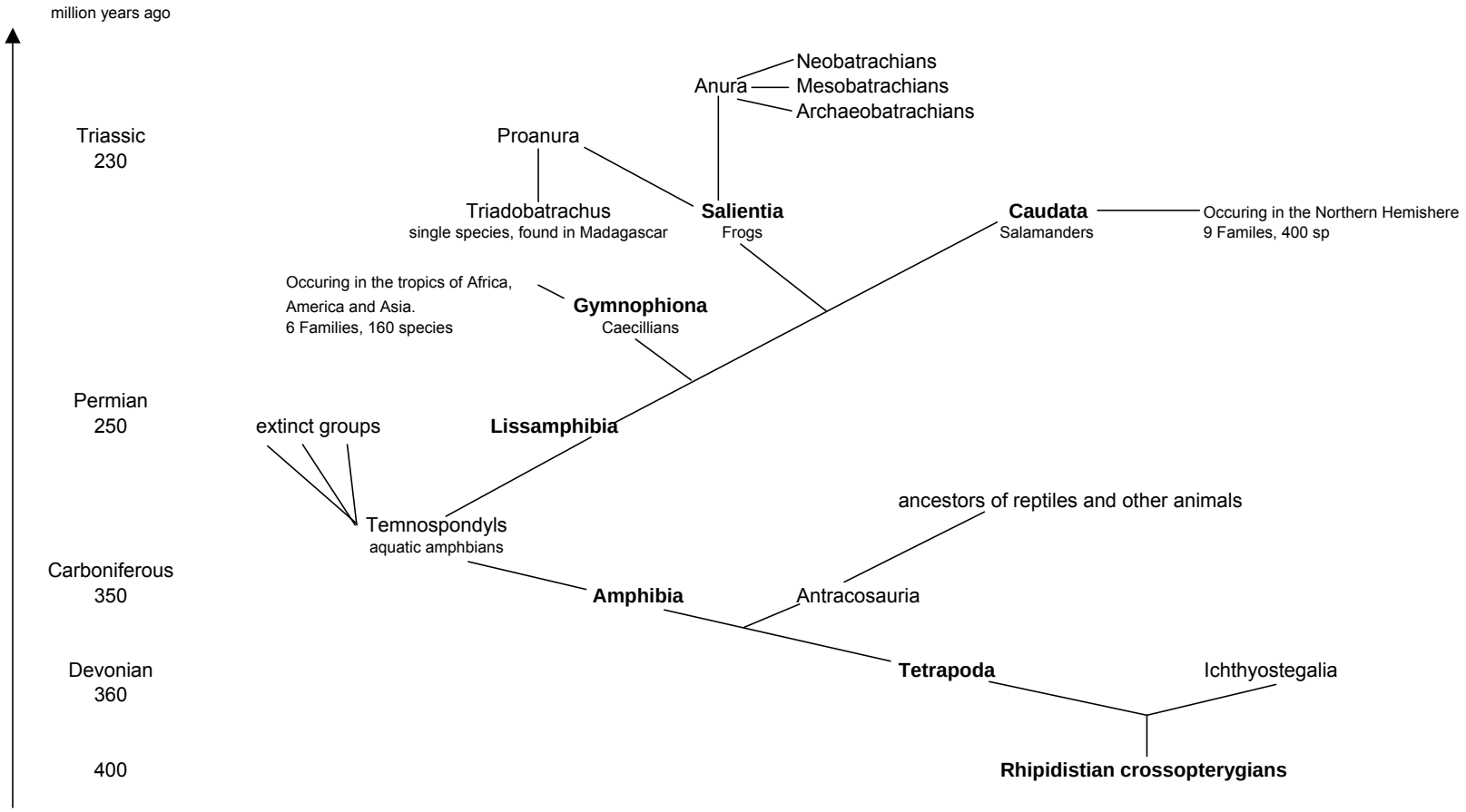

Figure 1.1 Amphibian Ancestry diagram. Note: time line is not to scale. Adapted from Zug (1993).

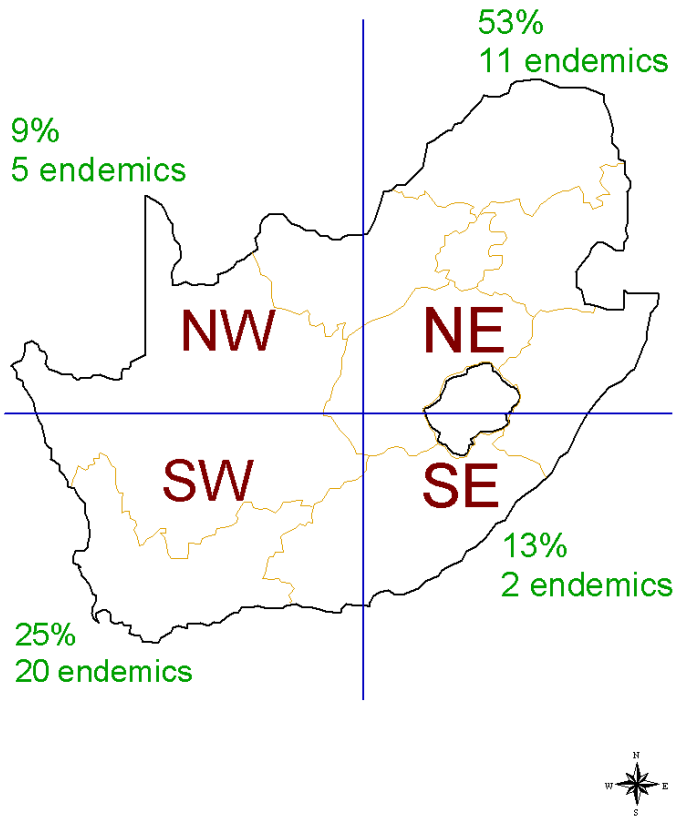

Figure 1.2 Distribution of South African frog species shown as a percentage per quarter.

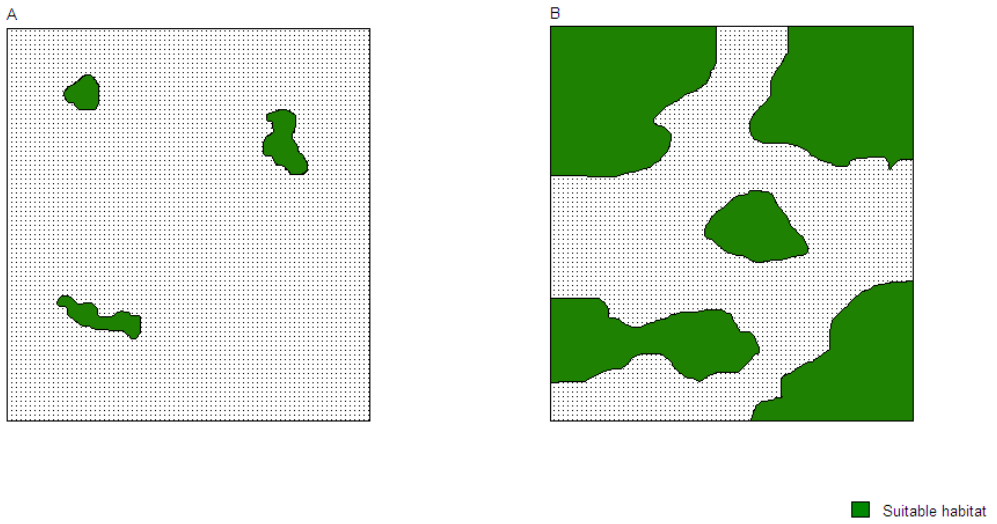

Figure 1.3 The quantity of remaining suitable habitat differs between habitat loss (A) and habitat fragmentation (B).

Chapter 2

The effect of land use on the species composition of amphibians in North Eastern KwaZulu-Natal

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Abstract

North-eastern KwaZulu-Natal is an area of high biodiversity as well as high development. To assess the effects of land-use on anuran species composition within this area, a stratified random sampling technique was applied. Species composition was examined over three strata namely: land use, season and habitat. The land use types surveyed were gum (*Eucalyptu*s sp.) plantations (four properties), sugar cane (*Saccharum officinarum*) farms (four properties) and conservation areas (five properties). Sampling was split into three sampling periods: early (Oct-Nov), mid (Dec-Jan) and late (Feb-Apr). Each property was sampled once during each of these periods, and three habitat types were sampled: open water bodies, wetland areas and grassland/woodland complexes. Pit-fall traps with drift-net fences and voice recordings were used to identify the species at each site. The average number of amphibian species found on conservation, sugar and gum sites was 13.2 ± 6.6; 3.8 ±1.3; and 2.8 ±1.4 respectively. A Correspondence Analysis (CA) produced eigen values of 0.526, 0.485, 0.435 and 0.363 for the first four axes respectively. These axes accounted for 41.5% of the total inertia. Sites within the CA were classified according to land use, season and habitat. Species were classified according to their dependency on water bodies. The sugar and gum plantations had a lower variation between sites, and a low variation in habitat type. The low species richness of

amphibians in the gum and sugar cane areas is most likely due to the lack of habitat for species that are either totally dependent or totally not dependent on water bodies. The absence of *Hyperolius marmoratus* and *Amietophrynus gutturalis* was the factor defining the first division (eigen value 0.498) produced by the TWINSPAN analysis. The two groups produced were significantly different in terms of land use, habitat and season. Consequently land use has an impact on amphibian species numbers and needs to be considered in management for their conservation.

Introduction

The life history and biological traits of amphibians make them sensitive to their environment. It is this sensitivity enables them to be used as indicators of environmental stress (Beebee 1996; Channing 1997; du Preez & Carruthers 2009). The noted decrease in the population numbers of amphibians globally, has alarmed scientists, as it may be indicative of our current global ecological status (Blaustein & Wake 1990; Wake 1991; Richards et al. 1993). Climate change, increase in ultraviolet light, use of pesticides, water pollution, introduction of alien species, habitat loss or modification, and emerging diseases all have been considered possible causes of these global declines (Anzalone et al. 1998; Lips 1998; Alford & Richards 1999; Channing 2001; Blaustein & Kiesecker 2002; Muths et al. 2003; Weldon & du Preez 2004; Cushman 2006).

In South Africa, research documenting a decline in amphibian populations is lacking. The country's first Frog Atlas illustrating the distribution of South African frogs, was only published in 2004 whilst previous population data is scarce for a large majority of species (Weldon & du Preez 2004). Despite the lack of species distribution records, there are local populations and species under threat of extinction (Carruthers 2001; Channing 2001). The status of Red Data species listed before 2004 has not improved, and since then more species have been identified as

threatened or near threatened (Branch & Harrison 2004). A large majority of species have a limited range and inhabit unique environments (Passmore & Carruthers 1979; Carruthers 2001; Channing 2001; du Preez & Carruthers 2009). These species are the most affected by habitat modification and loss (Branch & Harrison 2004). *Microbatrachella capensis*, *Pyxicephalus adspersus*, *Hemisus guttatus* and *Hyperolius pickersgilli* are examples of species that occupy specific habitats and are sensitive to changes in their environments (Branch & Harrison 2004). Change in land use, afforestation, wetland drainage and urban sprawl has resulted in a loss of habitat for many frog species and is the major cause of local population decline in South Africa (Channing 2001; Weldon & Du Preez 2004; Du Preez & Carruthers 2009).

Land use practices such as forestry and sugar cane (*Saccharum officinarum*) production change the vegetation structure within an area (Brenchley et al. undated public handout; Kotze 2004). This changes the microclimate and reduces the number of available zones for habitation. The landscape is changed from a diverse matrix to one of monoculture (Ash 1988). Regulations governing the cultivation of these products usually stipulate that wetlands remain unplanted (Conservation of Agricultural Resources Act No. 43 0f 1983). This may protect the functioning of the wetland, but does not necessarily facilitate the habitation of the area by certain animal species, which require a larger habitat comprising of the wetland and the area surrounding it (Semlitsch & Bodie 2003). There are many species of frogs that occupy other regions besides large permanent wetlands (Zug 1993; Dupuis & Steventon 1999; Carruthers 2001; Minter et al. 2004). Some require permanent water sources, like the fully aquatic frog *Xenopus laevis* (Measey 2004), or prefer shallow running rivers or streams (eg: *Amieta anglolensis*) (Channing 2004). Others only breed in small shallow temporary pools that are not recognised as wetlands or protected as such (eg: *Pxyicephalus adspersus*) (see Du Preez & Cook 2004). There are some species that do not rely on any water feature but live and breed amongst

the leaf litter, in trees, or in burrows under the ground (*eg: Breviceps mossambicus*) (Minter 2004). The protection of wetlands within sugar cane and forestry regions may not protect all species of amphibians (Semlitsch & Bodie 2003). These land use practices may still place certain species at risk (Branch & Harrison 2004).

In north eastern KwaZulu-Natal land use varies. It was noted as far back as the 1960s by Bass (1966) that:

"The influence of man on the vegetation of the area… has been most noticeable in the region from St. Lucia southwards. Sugar cane, pine and gum plantations have almost completely taken over the place of the natural vegetation except for the dune forest and occasional large pans such as at Richards Bay (Bass 1966, pg6)."

Bass (1966) studied frogs in a similar region to the present study. Since then human population, development and infrastructure have increased greatly here, and the land use types that cover most of the region are classified as residential, gum (*Eucalyptus* sp.) plantations and sugar cane (aerial photographs and spatial information from the Department of Agriculture).

Therefore the aim of the present study was to examine the effects of land use on the species composition of amphibians within the northern coastal region of KwaZulu-Natal in South Africa, by comparing the amphibian species composition on properties under (1) sugar cane cultivation, (2) forestry production, and those under (3) conservation. Further objectives were to identify any possible factors that may be responsible for the difference in species composition, and highlight any frog species that may be used as indicators of environmental stress. It was hypothesised that amphibian species composition differs with land use. It was predicted that high species numbers would be found in conservation areas compared with the other land use types.

Methods

Study Area

The study area was in north eastern KwaZulu-Natal, on the north eastern coast of South Africa (Fig 2.1), and ranged from approximately 32.00°S 27.75°E in the north western corner, 32.00°S 28.50°E in the south west, 32.45°S 27.75°E in the north east and 32.45°S 28.50°E in the south east. The study area incorporated the towns of Matubatuba, Hluhluwe and Mkhuze and was found within the vicinity of the iSimangaliso Wetlands Park, which is a World Heritage Site; and the iMfolozi Game Reserve. The eastern section of the study area comprised of the southern most extension of the Mozambique coastal plain, a flat, low lying region formed by marine deposits of the Indian Ocean and characterised by extensive sand dunes and sand forests (Bass 1966). This low lying plain gradually rises to above 100 m above sea level as it extends west, and becomes a more steeply graduated landscape, characterised by rolling hills and woodland savanna (Bass 1966). The area is fed by numerous catchments and distinguished by the major river systems of the Mfolozi, Nyalazi, Hluhluwe and Mkuze. Wetland systems dominate the region (Bass 1966).

The properties that were selected for the present study ranged fairly evenly from the north to the south of the study area, and represent sugar cane cultivation, gum plantation and conservation sites (Fig 2.2). Five were used as conservation sites. Iqina, the most northerly property, was a private game reserve on the Mkuze River. The vegetation ranged from riverine forest, some grassland and thornveld, savanna, and sand forest. Phinda Resources Reserve was a private game reserve, bordering on Mkhuze Game Reserve, and comprised of savanna, sand forest, riverine vegetation, and some grassland areas. Falaza Game Reserve was a private game reserve and the vegetation consisted mainly of sand forest Bonamanzi Game Reserve was a private game reserve, noted for it's bird biodiversity. The vegetation

ranged from sand forest, savanna, grassland to Lala palm veld. Lake Mavuya is a large wetland and lake region that falls under the management of the forestry company SAPPI. Part of the area is under conservation, the southern section is under gum plantation and directly opposite, on the northern bank is under sugar cane cultivation. This property is large and had four study sites within it, two plantation sites, a sugar cane site, and a conservation site. Silver Sands (sugar cane site) was a farm, comprising of mainly sugar cane cultivation, it had a large dam and a stream on the property. Palm Ridge was an organic sugar farm and was used as a sugar cane site. Mvubu dam and Lake Futululu were plantation sites owned by SAPPI, they were used as gum plantation sites. Bordering on Lake Futululu are also private sugar cane farms, the site referred to as Umfolozi in the data was in this region and used as a sugar cane site.

Stratification and site selection

A stratified random sampling technique was applied (Hayek 1994). The effects on Anuran distribution within the study area was examined across three levels, namely:

1. Land use type
2. Season
3. Habitat type

Within the study area three prevalent land use types were designated, namely: forestry plantations, sugar cane farms and conservation areas. To assess the impact of land use on the species composition of frogs, sampling occurred on various properties of these three main land use types. The study area was examined using 1:50 000 topographic maps. Dams, rivers, streams and wetland areas were mapped using ArcView 3.2 (Environment System Research Institute Inc. (ESRI), Redlands, California). The requirements used to select sites were: the presence of an open water body such as a dam or a pond; access by road; and distance from each other. Possible properties were noted and then viewed on site. Of the remaining

sites that were deemed appropriate, five conservation, four plantations, and four sugar cane sites were selected as mentioned previously.

Within the study area, spring and summer have the highest rainfall and average temperature (Schulze 1997). These factors facilitate breeding amongst frogs, render them more active and increase the likelihood of encounter (Hayek 1994). Different species of frogs have different breeding seasons (Passmore & Carruthers 1979; Carruthers 2001; Channing 2001; du Preez & Carruthers 2009). Not all species of frogs are therefore, active at the same time of year. Species composition changes as the season progresses (Bass 1966). To ensure that there was the chance of encountering all the possible species, the spring-summer was divided into three periods:

- The early period, October to the end of November
- The mid period, December to the end of January
- The late period, February to the end of April

Each site was sampled once during each of these periods. Sampling was conducted over the spring-summer of 2002/2003.

The frogs of this region inhabit a range of habitat types (Bass 1966; Passmore & Carruthers 1979; Carruthers 2001; Channing 2001; Minter et al. 2004; du Preez & Carruthers 2009). A species/habitat matrix was complied, using the available literature, to assist in the selection of habitat types to be sampled (Appendix 1). To ensure that all possible species could be encountered, the following habitat types were sampled:

- The perimeter of open water bodies (dams, ponds, pools)
- Wetlands
- Grassland or woodland complexes

Sampling occurred in each of these habitat types at each site. Within plantation and sugar cane sites the grassland or woodland type was replaced by sampling within the respective crop type.

Sampling

Sampling took place at each of the 13 sites for the duration of a one week during each time period (early/mid/late; see above) of the spring/summer season. Depending on the distance between sites, two or three sites were sampled simultaneously. Two different sampling methods were used to improve the likelihood of encountering all possible species. These methods were the recording of calls and drift-fence pit-fall traps.

During a pilot study it was evaluated that the most effective time to record calls within the study area was at approximately an hour after sunset, on evenings where temperatures were approximately greater than 20°C. Walked audio transects is the method that is generally recommended (Hayek 1994), but in the plantation sites, and at Silver Sands Sugar Cane Farm was prohibited for safety reasons. In order to maintain consistency, audio recordings were conducted from a vehicle at each of the three habitat types on each site. Recordings were taken for 10 min at five min intervals over a period of 45 min. During the sampling week, recordings were done twice at each site. Recording was done using a Sony MZ-N707 Net Mini-disk (MD) Walkman, with a Sony ECM-MS908C directional microphone. The frequency response of the microphone was 100-15 000 Hz, and was unidirectional at either 90° or 120°. The presence of the species vocalising was established and verified using a compact disc recording of South African frog calls (South African Frog Atlas Project, University of Cape Town, Cape Town). This was done at each habitat type on each property.

Within each habitat type on each site, a pit-fall trap was set up. These traps consisted of a 9*l* bucket and funnel set level to the surface. Leading up to the pit-fall trap three drift-fences of shade cloth (20% shade coverage) were erected. They were 1 m high and 5 m long, with the bottom edge buried to prevent animals from slipping under them (Fig 2.3). The total capture area was 84.95 m^2. At open water and wetland habitat types the trap was set up within one meter of the perimeter of the water. Within grassland/woodland, sugar cane and plantation habitat types the traps were set up in a random location in the middle of the vegetation type. The traps were placed at the same location during each sampling period. The traps were set up on the first day of the sampling week and were checked every morning for the next five successive days. The presence of each species trapped was recorded and verified.

Data analysis

A cluster analysis was performed using Multivariate Statistical Package (MVSP) (Kovach Computing Services, Anglesey, Wales); which classified sites in relation to each other according to their species composition. Sites where no species were found were eliminated before the classification was run. Two outlier species were also eliminated to reduce a skewed effect. The Unweighted Paired Group Method (UPGMA) using arithmetic means was applied (Sneath & Sokal 1973) to produce the clusters; in which the similarity between groups was calculated using Jaccards co-efficient (Ludwig & Reynolds 1988).

To illustrate the how the variance distribution between sites and species was distributed a Correspondence Analysis (CA) was performed using CANOCO 4.5 (Ter Braak 1987b). Two outlier species and the sites where no species were found were eliminated. The analysis was symmetrical and rare species were not down-weighted. A biplot of species and sites was plotted. Sites were classified according to land use, season and habitat type. A separate scatter plot was created for each of these

classifications. Envelopes were drawn around the groups to emphasize their distribution. Species were classified according to their dependency on water (Appendix 2) and envelopes were drawn around the three groups. A scatter plot was created for this classification.

To identify species that were responsible for each grouping of sites, TWINSPAN was used (Hill 1979). Two outlier species and sites with no species records were eliminated before analysis. Two dichotomous diagrams were produced, one showing the division of group according to their species composition; and one illustrating how species were related to each other. Chi-squared analysis was used to test if the grouping of sites at each division was independent of land use type, season and habitat type. To test if species groupings were independent of their dependency on water, chi-squared was used for each division.

A Generalized Linear Model (GLIM) (GenStat 13th Edition VSN International) was used by adding in the factors of season, land use and habitat to see which factors best predicted the presence/absence of a species. This was performed on species that had an occurrence of greater than 20% across all sites. In GenStat the usual regression model was transformed to a GLZ by changing the general model to a binomial model using the „Logit' function. The maximal model was set as „Landuse*Habitat*Season'. The fitted model was set as the constant, thereafter the factors were systematically added in the following order: land use, season, and habitat. This order follows the sampling stratifications.

Results

Species composition

There were more amphibian species on the conservation properties than on the sugar cane cultivation, and gum plantation properties (Table 2.1). The mean number

of species found differed with land use with conservation areas 13.2 ± 6.6, plantations 3.8 ± 1.3 and sugar cane 2.8 ± 1.4.

With the exception of a single amphibian species (*Arthroleptis wahlbergi* found at Lake Futululu), all the species found at the sugar and gum plantation sites were found in the conservation areas. Phinda Resources Reserve and Bonamanzi Game Reserve had the highest species richness with 23 and 20 species respectively, while Silver Sands sugar cane farm there were no species found (Table 2.1). The most common species found at all sites were *Hyperolius marmoratus*, *Amietophrynus gutturalis* and *Amietophrynus garmani*.

Classification

The classification of sites from the Cluster Analysis can be divided into five main groupings (Fig 2.4). The similarity between these groupings is measured on a scale of zero to one, where zero indicates no similarity and one denotes that the sites are identical. The similarity between cluster A and B was less than 0.05. Between clusters B and E it was less than 0.2, and approximately 0.2 between E and C. The similarity index between clusters C and D was approximately 0.3. This implies that there was a difference in species composition between the sites within these groupings.

The CA produced eigen values of 0.526, 0.485, 0.435 and 0.363 for the first four axes respectively. These axes accounted for 41.5% of the total inertia. The first and second axes accounted for 23.2% of the total inertia. A biplot of this ordination shows species in relation to sites (Fig 2.5). There was a large congregation of sites and species around the intercept of the first and second axes, with the remaining points scattered. The relationship between these sites was more clearly illustrated when the sites and species are classified according to certain aspects. When the sites were classified according to the clusters defined by the Cluster Analysis, four

distinct groups were formed (Fig 2.6). Cluster A consisted of mostly conservation sites of grassland/woodland habitat types. Cluster B of conservation sites of wetland habitats. Clusters C and D were composed of mainly open water habitat types, but C was comprised of the three land use types, while D was mainly conservation sites. The effects of land use, habitat and season on the species composition were illustrated when the sites were classified according to these factors (Fig 2.7). In terms of the effects of land use, the largest variation in species composition was found amongst conservation sites. There was less variation amongst plantation sites and even less between those under sugar cane (Fig 2.7a). The grassland/woodland habitat type was the most diverse, while there was less variation in species composition within open water and wetland habitat types (Fig 2.7b). Season showed the most overlap between the groupings, the late season had the greatest variation between sites, followed by the early and then the mid season (Fig 2.7c). All three scatter plots showed a similar pattern that was defined by conservation sites, grassland/woodland habitats and the late season sampling sites. The variation amongst conservation sites appeared to be defined by two groups. The first comprised of cluster A and E; and the second group was formed mainly by cluster B with some sites found within clusters C and D. Clusters A and E contained only sites within the grassland/woodland habitat type. Cluster B contained mainly wetland habitat types. There were few plantation, or sugar cane land use sites within either cluster A, E or B. This indicated that there was a lack of grassland/woodland and wetland habitats within these land use types.

To examine the distribution of species within the ordination, they were classified according to their dependency on water bodies (Appendix 2). This classification divided the species into three distinct groups (Fig 2.8). The largest variation within a group was shown by the species that were not dependent on water bodies. Species that are semi-dependent had the least variation in distribution. The

dispersal of these groups corresponds well with the distribution of the groups classified according to the Cluster Analysis (Fig 2.6). This prompted the use of water dependency to explain the species composition of the cluster analysis groupings. Clusters A and E had similar distribution to species that were not dependent on water bodies. This suggests that the species composition of the sites found in clusters A and E were defined by the presence of these species. In the same regard, cluster B was defined by species that are dependent on water bodies. Cluster C was defined by species from all water dependency groups, and cluster D by semi-dependent and non-dependent species. These species distributions further correlated with the habitat type distributions. Those species that were not dependent on water bodies were found within the same area on the ordination as the grassland/woodland habitat types (Clusters A and E). Species that were dependent on water bodies had a similar distribution as the wetland habitat types (cluster B). The species that were found in the intermediate range, that were semi-dependent on water bodies, were found within clusters C and D, which were defined by all habitat types.

The groups of sites produced by a TWINSPAN analysis were similar to those created by the Cluster Analysis and the CA ordination (Fig 2.9). The eigen value for the first division was 0.498, which indicated a fairly high degree of heterogeneity between the groups. The absence of *Hyperolius marmoratus* and *Amietophrynus gutturalis* was the factor defining the first two groups. These two species were found on the first and second axes of the CA ordination (Fig 2.5).

The second to sixth divisions produced eigen values of 0.402, 1.00, 0.357, 0.431 and 0.738 respectively. Chi-squared was used to test if the groups produced at each division were significant different in terms of the factors of land use, habitat and season. The groups produced by the first division were highly significantly different ($chi^2 < 0.005$) in land use, habitat and season. A significant difference ($0.025 > chi^2 > 0.01$) between the groups produced by the second division was found in season. The

groups from the third division were significantly different ($0.05 > chi^2 > 0.025$) in land use. Further division did not produce any significant differences in terms of land use, habitat or season. The species were also classified using TWINSPAN (Fig 2.10). The first division produced an eigen value of 0.443. The second to seventh divisions produced eigen values of 0.253, 0.626, 0.094, 0.146, 0.281 and 0.379 respectively. The groups produced by divisions 1, 2, 4, and 5 were significantly different ($p < 0.005$) in terms of water dependency allocations.

Correlation

A GLIM was fitted to those amphibian species that occurred in more than 20% of the sites. The model was fitted to four species, *Amietophrynus gutturalis, Amietophrynus garmani, Hyperolius marmoratus* and *Hyperolius tuberillingus*. The model for *H. tuberillingus* showed a significant change ($p < 0.001$) when land use and habitat were added as a factor. The addition of season had no significant effect. The models for *B. gutturalis, B. garmani* and *H. marmoratus* showed no significant change when season and land use were added. The models for these species indicated a significant change ($p < 0.001$) when habitat was added as a factor.

Discussion

The effect of land use

There was a difference in amphibian species richness and diversity between land use types as hypothesised. More species were found in conservation areas than in gum plantation, and sugar cane land use types as predicted. The relationship between land use type, habitat, and species dependency on water bodies explained the lower species richness on gum plantation and sugar cane sites. The species that were not totally dependent on water bodies (that inhabit grasslands, woodlands or forest regions) and the species that are completely dependent on open-water, were

not represented in the plantation and sugar sites. This suggested that the process of sugar cane and gum cultivation has disturbed or replaced the habitats needed by these species. Plantation and sugar cane sites in this study lacked the wetland and grassland/woodland habitats, and the amphibian species that are found within these habitats were not found on these properties. This explained why habitat was the significant factor explaining the distribution of the most abundant species. These two land uses are monocultures, and sugar cane is burnt regularly (pers. obs.).

The effect of habitat removal on species composition and amphibian declines has been well documented (Alford & Richards 1999). Habitat destruction and modification is most likely the cause of more declines in populations than any other factor (Blaustein 1994). Frogs are entirely dependent on a suitable habitat and the biggest threat to them is habitat destruction (Behangana 2004). One of Diamond's (1989) four principal causes of species extinctions is habitat fragmentation. Agriculture results in habitat modification and fragmentation. In the mid-western United States there has been a noted decrease in amphibian numbers that corresponds with the growth of agriculture in the region since the settlement of Europeans (Lannoo 1998). This decline in amphibian numbers within this area has matched wetland loss over the past 200 years, loses which range from 85-90% (Dahl 1990).

The removal of vegetation and modification of its structure during forestry has caused amphibian declines (Ash 1988). Logging practices exposes terrestrial species and alters the microclimate; it also causes the siltation of streams, which affects aquatic species (Corn and Fogleman 1984; Corn and Bury 1989; Welsh 1990; Ash 1997). Welsh and Ollivier (1998) found that siltation caused by logging decreased the abundance of amphibian species. The draining of wetland removes breeding sites (Johnson 1992) and fragments the population (Semlitsch & Bodie 1998). In Britain the population of *Bufo calamita* was found to decrease over 40 years due to shifts in land use (Beebee, 1977).

Forestry companies and agriculturists within South Africa recognise the importance of wetlands for maintaining water quality (Cowan 1995; Kotze 1996). Most practices avoid cultivation through wetlands and, in addition, leave a buffer zone around it (Cowan 1995; Kotze 2004). The effect of agriculture on wetlands and the subsequent consequence for amphibians in the United States showed that the protection of wetlands is of little value if the surrounding terrestrial environment is destroyed (Semlitsch 1998). Later studies projected the core zone that is used by amphibian populations to extend as far as 290 m from the wetland edge (Semlitsch & Bodie 2003). The buffer zone distance for wetlands in South Africa, which is required by law, is 10 m from the edge of the wetland (Conservation of Agricultural Resources Act 43 of 1983, Department of Water Affairs and Forestry), this is a suitable buffer zone to protect the basic functioning of the wetland (Kotze 2004), but may not be sufficient to protect the amphibian biodiversity. These issues are further explored in Chapter 3.

Amphibians are able to recolonise an area following an environmental disturbance, provided that the area has been recovered and rehabilitated (Alford & Richards 1999). The key to this ability is the presence of areas adjacent to the affected region suitable for habitation by the displaced species (Werner et al. 2007). This highlights the need for conservation areas within regions under cultivation with corridors joining them. In particular the areas under conservation need to contain all relevant habitat types to support the various species that should be found in that vicinity. Size and frequency of these conservation areas still needs to be determined in the context of most South African amphibian species.

Indicator species

An indicator species is one that displays a sensitivity to changes within it's environment (Townsend et al. 2003). A good indicator is a species that is abundant; easily identifiable; sensitive to ecosystem stress; whose natural variation in numbers

can be distinguished from those caused by ecosystem dysfunction (Rapport 1992; Welsh & Ollivier 1998; du Preez & Carruthers 2009; Griffiths et al. 2010). The indicator species that defined the significant division of sites in terms of land use, season and habitat were *Hyperolius marmoratus* and *Amietophrynus gutturalis*. Habitat was found to be a highly significant factor responsible for their distribution. *Amietophrynus gutturalis* has wide distribution across South Africa, and is found in large numbers (Carruthers 2001; Channing 2001; du Preez & Carruthers 2009). It is a species that is semi-dependent on open water bodies (Appendix 2), and is found in a range of habitat types. It is an opportunist species and is often found in regions inhabited by humans. It would not make a good indicator of environmental stress as it is found in region of high human impact. *Hyperolius marmoratus* is also an abundant species, and has a wide distribution across South Africa (Passmore & Carruthers 1979; Carruthers 2001; Channing 2001; du Preez & Carruthers 2009). It is dependent on water bodies (Appendix 2) and is limited to wetland habitats. It is a viable candidate for use of as an indicator species. High abundance and specialised habitat requirements are factors that are needed by good indicator species (Welsh & Ollivier 1998). It is also very distinctive and easy to identify, both visually and aurally (Channing 2001).

Hyperolius marmoratus, however, is mainly found in wetlands (Carruthers 2001; Channing 2001), consequently as an indicator of environmental degradation it would only reflect the damage done to wetlands. Though wetlands are an important part of an ecosystem, the application of indicator species needs to be holistic to be effective (Rapport 1992). It follows this approach to suggest the use of more than one species as indicators. This would allow a better understanding of the effects of a disturbance on the ecosystem as a whole. It would also allow isolation of a probable cause. If, within the ecosystem as a whole, a species that was dependent on water bodies was experiencing a decrease in abundance then it could be assumed that the problem was one of water quality. If a species that was not dependent on water

bodies was declining, then the problem could be one of habitat removal or modification. Species composition may be used as an indicator of environmental stress. To facilitate this, the species richness and diversity of a region needs to be measured before the effects of environmental events can be understood. The use of the species composition of amphibians as an indication of the state of ecosystems within South Africa is an aspect that would merit further research. This study has only used data that has shown the presence or absence of a species within a site, it did not take into account the numbers of individuals within a population. Species density data would better enable the tracking of changes within an area, as by the time a species has become locally extinct, much environmental damage may have already taken place.

Conclusion

The species composition of amphibians in this study was affected by the land use type. There were notably fewer species found on sugar cane and forestry sites than within conservation areas. This difference may be attributed to removal of the habitat supporting water dependent and totally non-dependent species. There were fewer suitable wetland and grassland/woodland habitats available for these frog species on sugar cane, and gum plantation land use types. In terms of using amphibians as bio-indicators, it was found that examining species composition as a whole might be a better indicator of environmental stress than the presence or absence of a single species. Examining the species composition according to the species water dependency groups may indicate where a possible ecosystem disturbance has occurred.

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Table 2.1 Species found at each land use type. The presence of each species is indicated by a „X' and is recorded for all habitat types on each property throughout the whole season.

	Conservation					Sugar				Plantation			
	Bonamanzi	Falaza	Phinda	L.Mavuya	Iqina	L.Mavuya	Umfolozi	Palm Ridge	Silver Sands	L.Mavuya 1	Mvubu dam	L.Futululu	L.Mavuya 2
Species	C1	C2	C3	C4	C5	S1	S2	S3	S4	P1	P2	P3	P4
Afra angl						x							
Atrh sten	x	x	x										
Atrh wahl												x	
Afri deli													
Brev adsp	x		x										
Bufo garm	x	x	x	x	x	x	x	x			x		
Bufo gutt	x	x	x	x	x	x	x	x			x	x	x
Chri xera	x	x	x		x								
Hemi marm	x	x	x		x						x		x
Hemi gutt		x	x										
Hype argu	x		x										
Hype marm	x	x	x	x	x	x	x	x		x	x	x	x
Hype nast			x										
Hype pick	*												
Hype pusi	x	x	x		x								
Hype semi	x												
Hype tube	x	x	x	x	x						x		x
Kass sena	x		x										
Lept moss	x		x										
Phry nata	x	x	x	x			x			x			
Ptyc anch	x												
Ptyc moss			x										
Ptyc oxyr	x	x	x										
Pyxi edul	x		x								x		
Schi care	x		x										
Tomo cryp			x										
Tomo krug			x										
Tomo nata	x		x										
Xeno laev	x		x										
Total	20	11	23	5	7	4	4	3	0	2	6	3	4

* There was a possible capture of *Hyperolius pickersgilli*, at Bonamanzi but a positive identification could not be included

Figure Legends

Figure 2.1 Location of study area within the African continent and within South Africa.

Figure 2.2 Location of properties within the study area.

Figure 2.3 Top-view (A) of pit-fall trap showing drift fence layout; side view (B), bucket and funnel buried to ground level.

Figure 2.4 Sites classified by species composition using a Cluster Analysis applying the Unweighted Paired Group Method (UPGMA). The similarity between sites was calculated using Jaccards co-efficient, where value of zero indicates no similarity and identical sites have a value of one. The labels of each site are a composite of the season (1: early, 2: mid, 3: late); land use type (C1-5 conservation properties, S1-4: sugar cane properties, P1-4: gum plantations); and habitat type (ow: open water, gw: grassland/woodland, wet: wetland). For example 3C5gw is a sample taken during the late season at a conservation site in a grassland/woodland habitat.

Figure 2.5 CA**-** Biplot of species encountered in relation to sites. Species found in the same region were grouped (Group 1-4, see appendix 3 for site lists). The labels of each site are a composite of the season (1: early, 2: mid, 3: late); land use type (C1-5 conservation properties, S1-4: sugar cane properties, P1-4: gum plantations); and habitat type (ow: open water, gw: grassland/woodland, wet: wetland). For example 3C5gw is a sample taken during the late season at a conservation site in a grassland/woodland habitat. Note: Kasssena should be Kassisene; Bufogarm should be Amiegarm, Bufogutt should be Amiegutt

Figure 2.6 CA-Scatter plot: sites classified according to the divisions defined by the cluster analysis: cluster A (●); cluster B (□); cluster C (✦); cluster D (▲); cluster E (○). (Group 1-4, see appendix 3 for site lists). The labels of each site are a composite of the season (1: early, 2: mid, 3: late); land use type (C1-5 conservation properties, S1-4: sugar cane properties, P1-4: gum plantations); and habitat type (ow: open water, gw: grassland/woodland, wet: wetland). For example 3C5gw is a sample taken during the late season at a conservation site in a grassland/woodland habitat.

Figure 2.7 CA-Scatter plots, sites grouped according to land use (A), habitat (B) and season (C). **A: sites grouped according to land use**: conservation sites (○); gum plantations (▲); sugar cane (■). The labels of each site are a composite of the season (1: early, 2: mid, 3: late); and habitat type (ow: open water, gw: grassland/woodland, wet: wetland). For example 3gw is a sample taken during the late season in a grassland/woodland habitat. **B: sites grouped according to habitat**: open water (○); grassland/woodland (▲); wetlands (■). The labels of each site are a composite of the season (1: early, 2: mid, 3: late); and land use type (C: conservation, P: gum plantations, S: sugar cane properties). For example 3C is a sample taken during the late season on a conservation property. **C: sites grouped according to season**: early, Oct-Nov (■); mid, Dec-Jan (▲); late, Feb-Apr (○). The labels of each site are a composite of the land use type (C: conservation, P: gum plantations, S: sugar cane properties) and habitat type (ow: open water, gw: grassland/woodland, wet: wetland). For example Cgw is a sample taken on a conservation property in a grassland/woodland habitat.

Figure 2.8 CA-scatter plot: species classified according to water dependency: totally dependent (▲); semi-dependent (●); non-dependent (○). Labels are composed of the first four letters of the

genus name and the first four letters of the species name, for example „Hemigutt' refers to *Hemisus guttatus.* Note: Kasssena should be Kassisene; Bufogarm should be Amiegarm, Bufogutt should be Amiegutt

Figure 2.9 TWINSPAN diagram classifying sites according to species composition. The indicator species for each division are shown. The labels of each site are a composite of the season (1: early, 2: mid, 3: late); land use type (C1-5 conservation properties, S1-4: sugar cane properties, P1-4: gum plantations); and habitat type (ow: open water, gw: grassland/woodland, wet: wetland). For example 3C5gw is a sample taken during the late season at a conservation site in a grassland/woodland habitat. (○). Labels are composed of the first four letters of the genus name and the first four letters of the species name, for example „Hemi marm' refers to *Hemisus marmoratus.*

Figure 2.10 TWINSPAN diagram showing the classification of species. Species water dependency groupings are shown (Appendix 2). Labels are composed of the first four letters of the genus name and the first four letters of the species name, for example „Hemi marm' refers to *Hemisus marmoratus.*

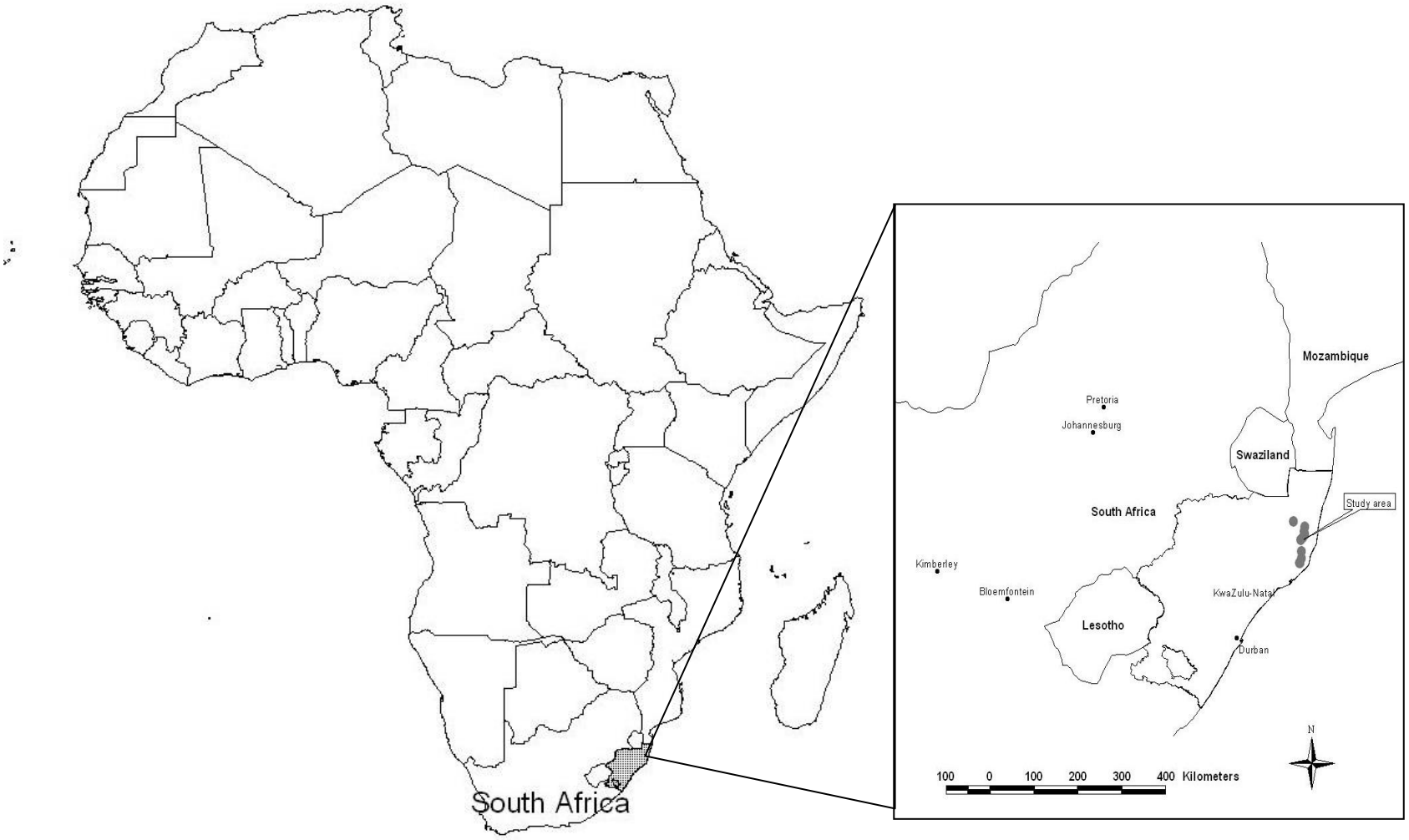

South Africa
Mozambique
Pretoria
Johannesburg
Swaziland
South Africa
Study area
Kimberley
Bloemfontein
KwaZulu-Natal
Lesotho
Durban
N
100 0 100 200 300 400 Kilometers

Figure 2.1

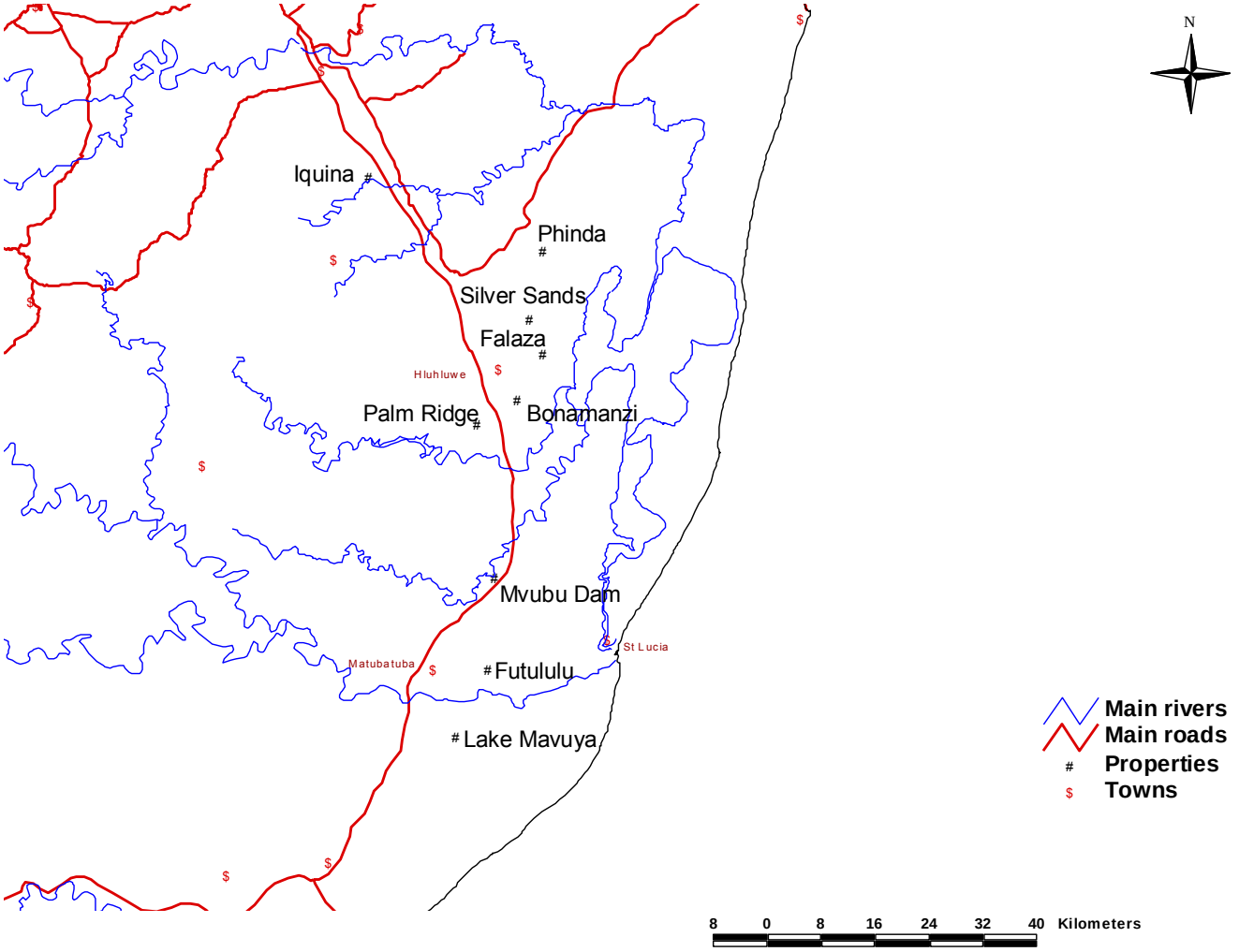
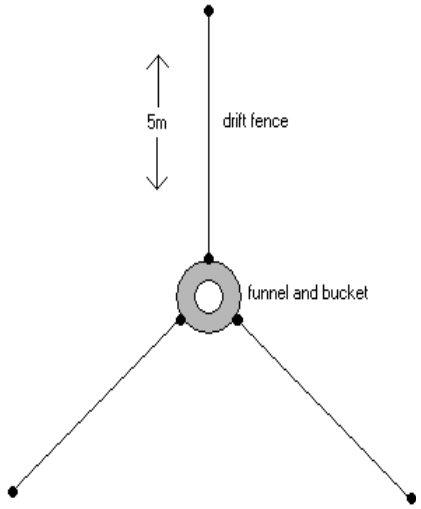

Iquina
Phinda
Silver Sands
Falaza
Hluhluwe
Palm Ridge
Bonamanzi
Mvubu Dam
St Lucia
Matubatuba
Futululu
Lake Mavuya
N
Main rivers
Main roads
Properties
Towns
8 0 8 16 24 32 40 Kilometers

Figure 2.2

A



B

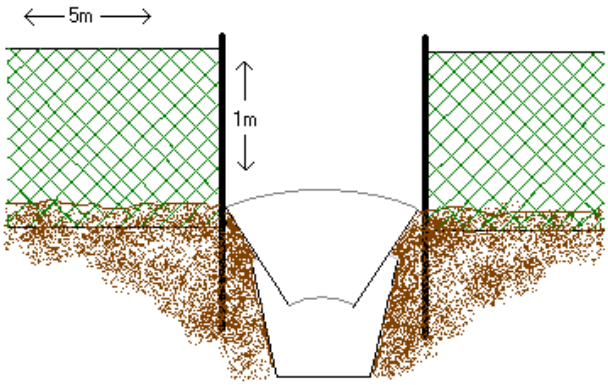


Figure 2.3

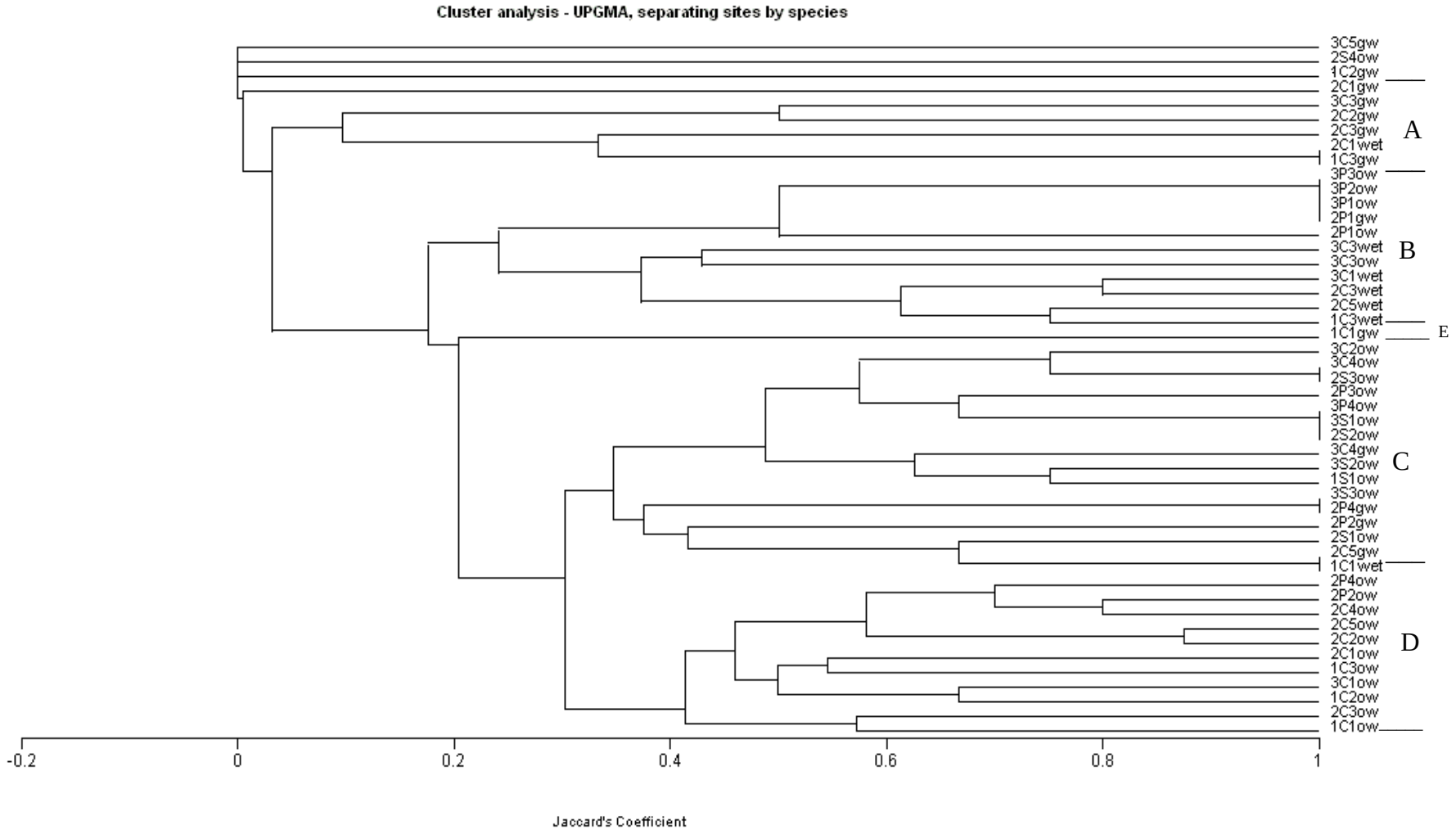

Cluster analysis - UPGMA, separating sites by species
3C5gw
2S4ow
1C2gw
2C1gw
3C3gw
2C2gw
2C3gw
2C1wet
1C3gw
3P3ow
3P2ow
3P1ow
2P1gw
2P1ow
3C3wet
3C3ow
3C1wet
2C3wet
2C5wet
1C3wet
1C1gw
3C2ow
3C4ow
2S3ow
2P3ow
3P4ow
3S1ow
2S2ow
3C4gw
3S2ow
1S1ow
3S3ow
2P4gw
2P2gw
2S1ow
2C5gw
1C1wet
2P4ow
2P2ow
2C4ow
2C5ow
2C2ow
2C1ow
1C3ow
3C1ow
1C2ow
2C3ow
1C1ow
A
B
E
C
D
-0.2
0
0.2
0.4
0.6
0.8
1
Jaccard's Coefficient

Figure 2.4

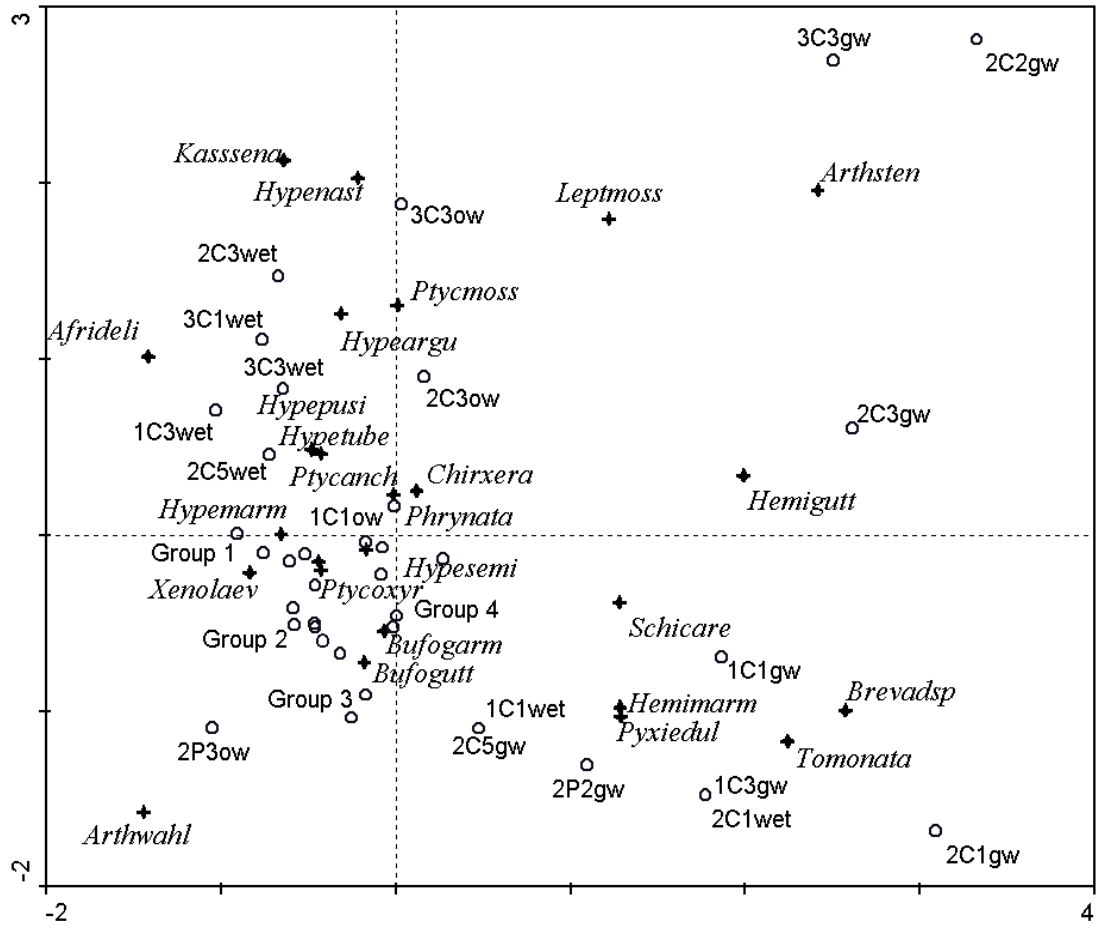

3
-2
-2
4
3C3gw
2C2gw
Kasssena
Hypenasi
3C3ow
Leptmoss
Arthsten
2C3wet
Ptycmoss
Afrideli
3C1wet
Hypeargu
3C3wet
2C3ow
2C3gw
Hypepusi
1C3wet
Hypetube
2C5wet
Ptycanch
Chirxera
Hemigutt
Hypemarm
1C1ow
Phrynata
Group 1
Hypesemi
Xenolaev
Ptycoxyr
Group 4
Schicare
Group 2
Bufogarm
1C1gw
Bufogutt
Brevadsp
Group 3
1C1wet
Hemimarm
Pyxiedul
2C5gw
Tomonata
2P3ow
2P2gw
1C3gw
2C1wet
Arthwahl
2C1gw

Figure 2.5

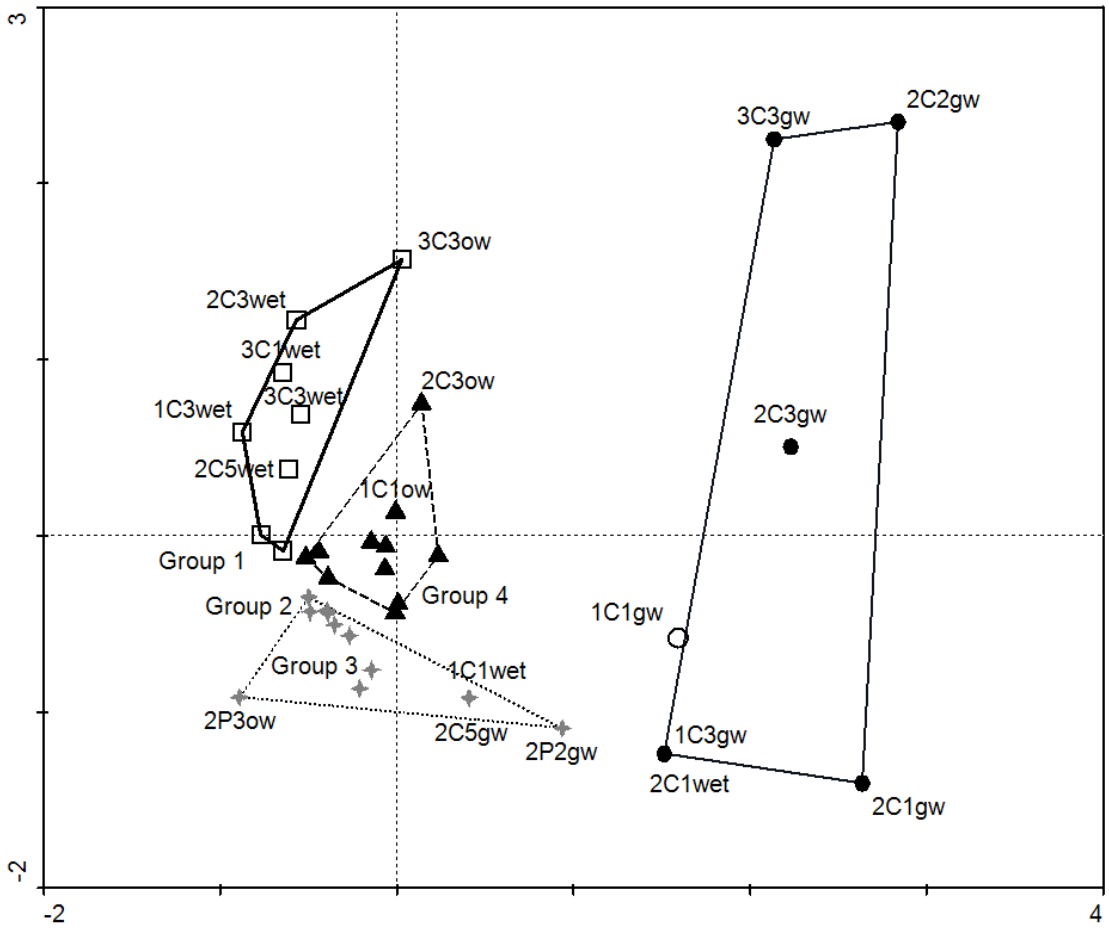

3
-2
-2
4
3C3ow
2C3wet
3C1wet
3C3wet
1C3wet
2C3ow
2C5wet
1C1ow
Group 1
Group 2
Group 3
Group 4
2P3ow
1C1wet
2C5gw
2P2gw
3C3gw
2C2gw
2C3gw
1C1gw
1C3gw
2C1wet
2C1gw

Figure 2.6

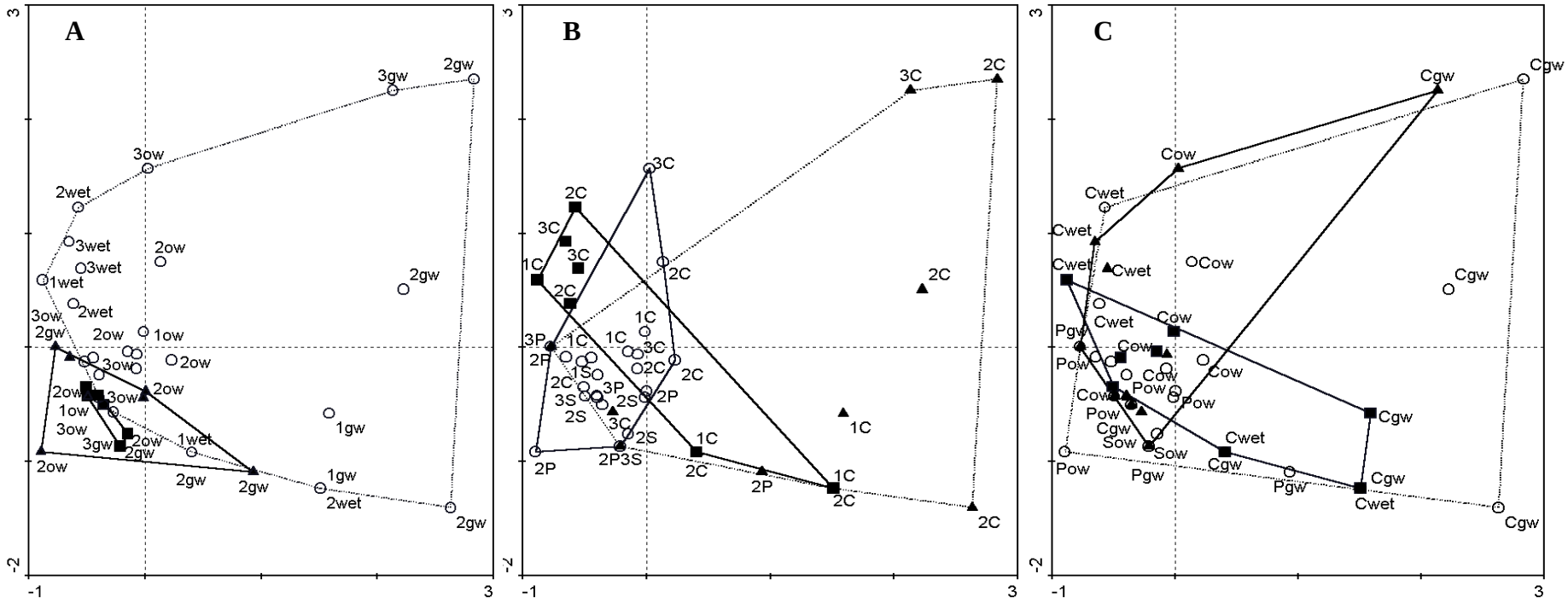

A
B
C
3
-2
-1
3
3gw
2gw
3ow
2wet
3wet
2ow
1wet
2gw
1ow
1gw
2C
3C
2P
1C
2S
3P
3S
Cgw
Cow
Cwet
Pgw
Pow
Sow

Figure 2.7

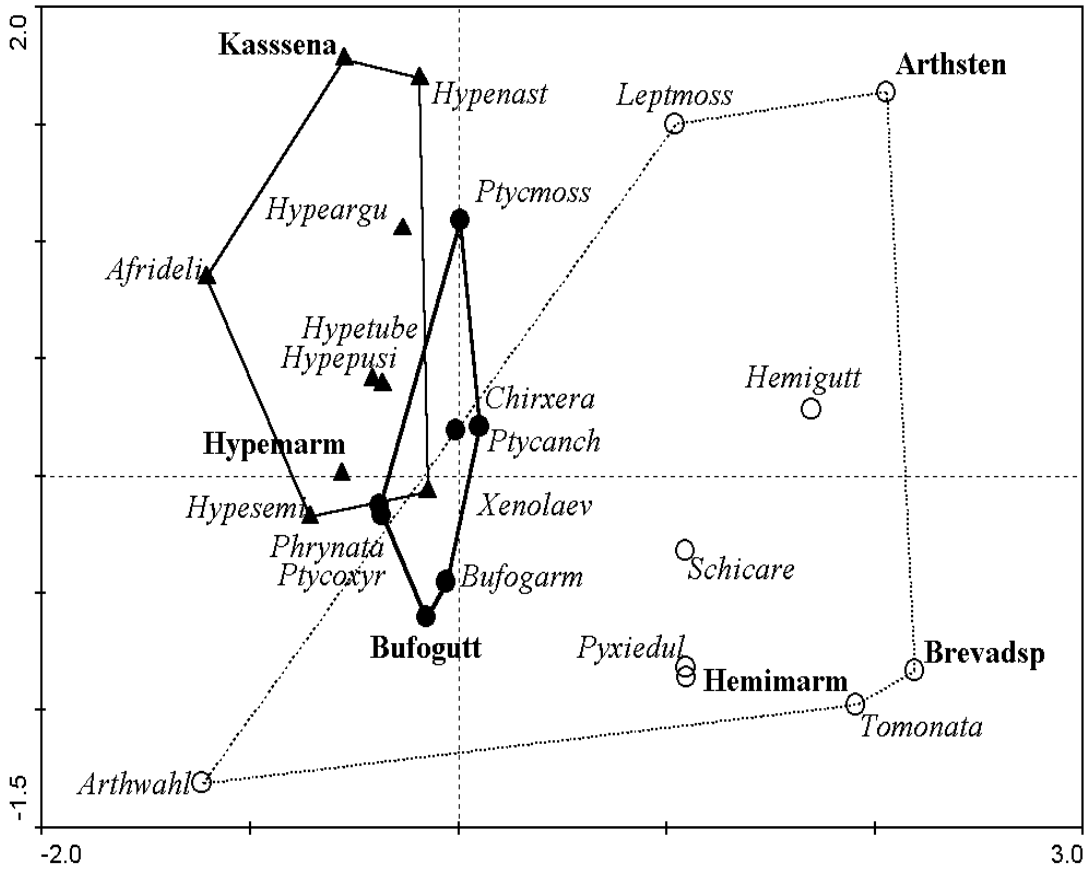

2.0
-1.5
-2.0
3.0
Kasssena
Hypenast
Leptmoss
Arthsten
Ptycmoss
Hypeargu
Afrideli
Hypetube
Hypepusi
Hemigutt
Chirxera
Ptycanch
Hypemarm
Hypesemi
Xenolaev
Phrynata
Ptycoxyr
Bufogarm
Schicare
Bufogutt
Pyxiedul
Brevadsp
Hemimarm
Tomonata
Arthwahl

Figure 2.8

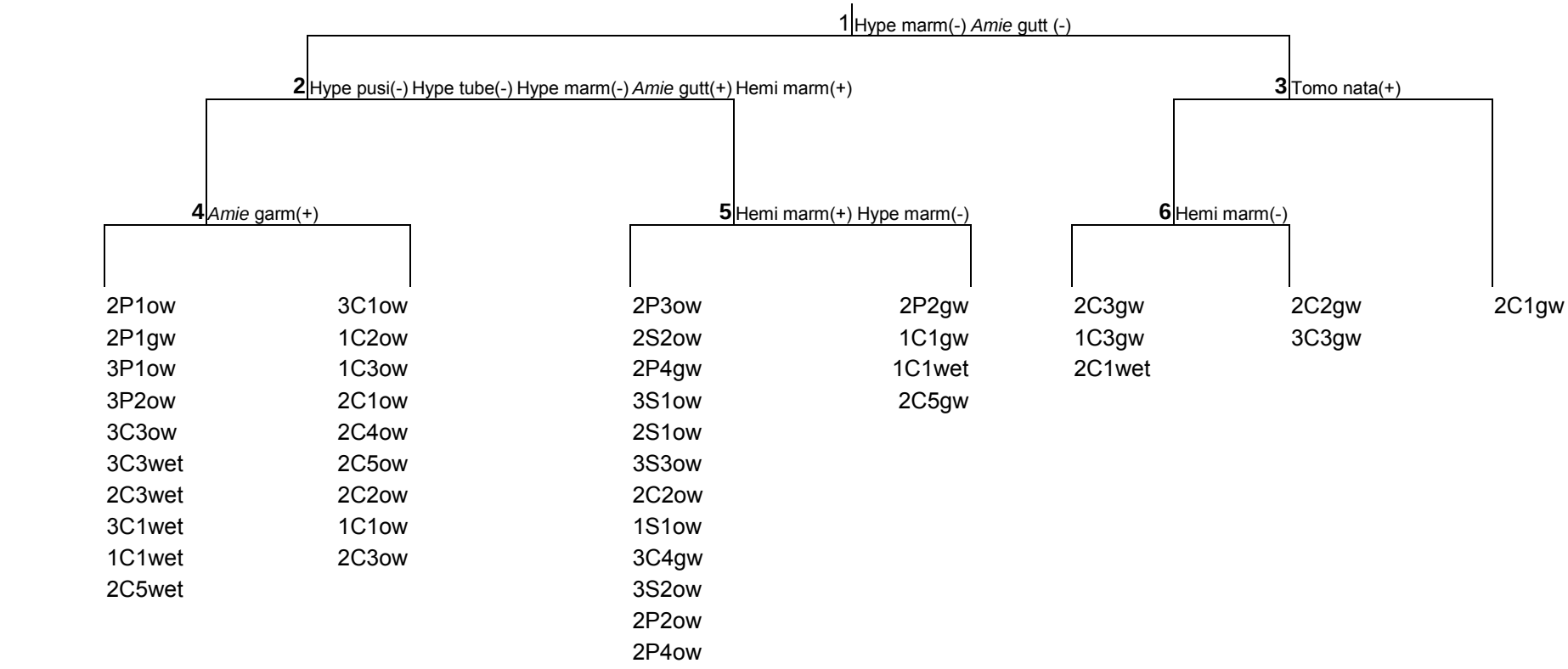

-ve
+ve
1 Hype marm(-) *Amie* gutt (-)
2 Hype pusi(-) Hype tube(-) Hype marm(-) *Amie* gutt(+) Hemi marm(+)
3 Tomo nata(+)
4 *Amie* garm(+)
5 Hemi marm(+) Hype marm(-)
6 Hemi marm(-)
2P1ow
2P1gw
3P1ow
3P2ow
3C3ow
3C3wet
2C3wet
3C1wet
1C1wet
2C5wet
3C1ow
1C2ow
1C3ow
2C1ow
2C4ow
2C5ow
2C2ow
1C1ow
2C3ow
2P3ow
2S2ow
2P4gw
3S1ow
2S1ow
3S3ow
2C2ow
1S1ow
3C4gw
3S2ow
2P2ow
2P4ow
2P2gw
1C1gw
1C1wet
2C5gw
2C3gw
1C3gw
2C1wet
2C2gw
3C3gw
2C1gw

Figure 2.9

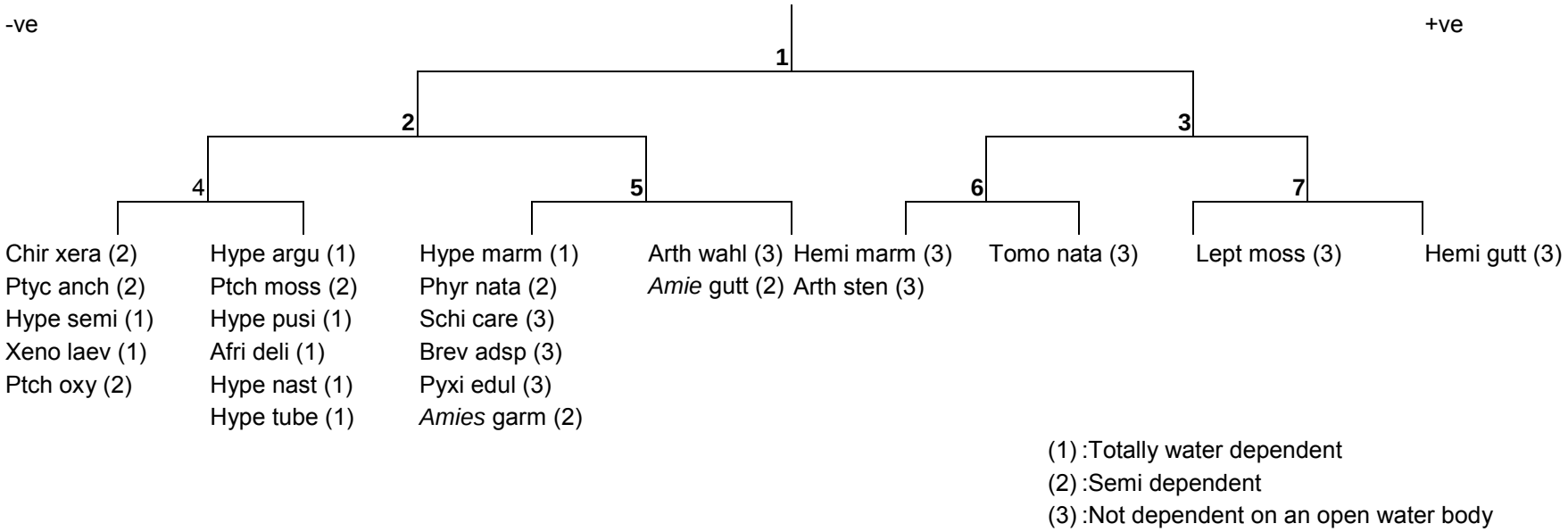

-ve
+ve
1
2
3
4
5
6
7
Chir xera (2)
Ptyc anch (2)
Hype semi (1)
Xeno laev (1)
Ptch oxy (2)
Hype argu (1)
Ptch moss (2)
Hype pusi (1)
Afri deli (1)
Hype nast (1)
Hype tube (1)
Hype marm (1)
Phyr nata (2)
Schi care (3)
Brev adsp (3)
Pyxi edul (3)
Amies garm (2)
Arth wahl (3)
Amie gutt (2)
Hemi marm (3)
Arth sten (3)
Tomo nata (3)
Lept moss (3)
Hemi gutt (3)
(1) :Totally water dependent
(2) :Semi dependent
(3) :Not dependent on an open water body

Figure 2.10

Appendix 1 Species Habitat Matrix where 1 indicates the presence of a species

	Habitat types							
Species	PW	TW	G/S	R	V/M	IG	F/W	T
Arth hewetti			1		1	1		
Amie fenoulheti		1	1					
Phry bifasciatus		1	1		1			
Pyxi adspersus		1	1		1			
Pyxi edulus		1	1		1			
Afri aurens		1		1	1			
Afri delicatus		1		1	1			
Afri fornasinii		1	1	1	1			
Afri spinfrons		1	1	1	1			
Hype argus		1	1	1	1			
Hype marmoratus		1	1	1	1			
Hype pikersgilli		1	1	1	1			
Hype pursillus		1	1	1	1			
Hype tuberlinguis		1	1	1	1			
Kass maculata		1	1	1	1			
Kass senegalensis		1	1	1	1			
Xeno muelleri		1	1	1	1			
Caco nanum		1	1	1	1			
Hype nasutus		1	1	1	1	1		
Semn wealii		1	1	1	1	1		
Caco boettgeri		1	1	1	1	1		
Phry acridoides		1	1	1	1	1		
Phry mababiensis		1	1	1	1	1		
Phry natalensis		1	1	1	1	1		
Tomo cryptotus		1	1	1	1	1		
Tomo krugerensis		1	1	1	1	1		
Tomo natalensis		1	1	1	1	1		
Chir xerampelina	1	1	1	1	1	1		1
Ptyc porosissima	1	1	1	1	1	1		
Ptyc taenioscelis	1	1	1	1	1	1		
Ptyc anchietae	1	1	1	1	1	1		
Ptyc mossambica	1	1	1	1	1	1		
Stro grayii	1	1	1	1	1	1		
Hype semidiscus	1	1	1	1	1			
Ptyc mascareniensis	1	1	1	1	1			
Ptyc oxyrhynchus	1	1	1	1	1			
Hild ornata	1	1			1			
Lept mossambicus	1	1			1		1	1
Nata bonebergi	1	1					1	
Hele natalensis	1	1					1	
Lept natalensis	1	1					1	1
Schi Carens	1	1	1					1
Amie rangeri	1	1	1					
Amie maculatis	1	1	1					
Hemi guttatis	1	1	1					
Hemi Maroratus	1	1	1					
Amie garmani	1	1	1					
Amieta angolensis	1	1	1					
Stro wageri	1	1	1					
Stro fusciatus	1		1		1			
Amie gutturalis	1		1					
Amie pardalis	1							
Xeno laevis	1							

PW = permanent water
TW = temporary water
R = Reed bed
V/M = vleis and marshes
IG = inundated grass
F/W = forest and woodland
G/S = grassland and savanna
T = in trees

Appendix 2 Life history table and habitat matrix

Species	Breeding period	Breeding habitat	Water dependancy group
Afrana angolensis	all summer	open water	1
Afrixalus aurens	all summer	vleis/pans	1
Afrixalus delicatus		vleis/pans	1
Afrixalus fornasinii	early-mid	swamps/streams	1
Arthroleptis stenodactylus			3
Arthroleptis wahlbergi			3
Breviceps adspersus	Early	burrows	3
Amieta fenoulheti		open water	2
Amieta garmani	early-mid	vleis/pans	2
Amieta gutteralis	all summer	open water	2
Amieta maculatus		open water	2
Cacosternum boettgeri	early-mid	vleis/pans	2
Chiromantis xerampelina	early-mid	trees overhanging water	2
Hemisus guttatus		burrows	3
Hemisus marmoratus	Early	vleis/pans	3
Hyperolius argus	all summer	reed beds	1
Hyperolius marmoratus	all summer	reed beds	1
Hyperolius nasutus		vleis/pans	1
Hyperolius pickersgilli	Late	open water	1
Hyperolius pusillius	all summer	vleis/pans	1
Hyperolius semidiscus	early-mid	reed beds	1
Hyperolius tuberilinguis		vleis/pans	1
Kassina maculata		vleis/pans	1
Kassina senagalensis		open water	1
Leptopelis mossambicus	Early	muddy hole	3
Leptopelis xenodactylus		muddy nest	3
Phrynobatrachus acridoides	mid-late	open water	2
Phrynobatrachus mababiensis	all summer	open water	2
Phrynobatrachus natalensis	early-mid	open water	2
Phrynomantis bifasciatus	rainy season	open water	2
Ptychadena anchietae	rainy season	open water	2
Ptychadena mascareniensis	rainy season	open water	2
Ptychadena mossambica			2
Ptychadena oxyrhynchus	rainy season	open water	2
Ptychadena porosissima	rainy season	open water	2
Ptychadena taenioscelis		open water	2
Pyxicephalus edulus	rainy season	open water	3
Schismaderma carens	Early	open water	3
Strongylopus grayii	rainy season	under rocks and leaves	2
Tomopterna cryptotus		open water	3
Tomopterna kurgerensis			3
Tomopterna natalensis		streams	3
Xenopus laevis		open water	1
Xenopus muelleri		open water	1

1= completely dependent on water bodies

2= semi-dependent on water bodies

3= not dependent on water bodies

(blank spaces indicate unknown information)

*smilplified table compiled from information from Passmore and Carruthers (1979), Carruthers (2001) and Channing (2001).

Appendix 3 List of sites found in CA groupings

Group 1	Group 2	Group 3	Group 4
3P1ow	2P1ow	3S2ow	3C1ow
2P1gw	3P2ow	3C2ow	2C2ow
3P3ow	1S1ow	2S3ow	2C5ow
	3P4ow	3C4ow	2P2ow
	2S20w	3C4gw	
	3S1ow	2S1ow	
	2C1ow	2P4ow	
	1C2ow	3S3ow	
	2C4ow	2P4gw	
	1C3ow		

The labels of each site are a composite of the season (1: early, 2: mid, 3: late); land use type (C1-5 conservation properties, S1-4: sugar cane properties, P1-4: gum plantations); and habitat type (ow: open water, gw: grassland/woodland, wet: wetland). For example 3P1ow is a sample taken during the late season at a plantation site in an open water habitat.

Chapter 3

The use of wetland buffer zones within sugar and gum plantations to facilitate the conservation of amphibians in North Eastern KwaZulu-Natal

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Formatted for Conservation Biology.

Abstract

The buffer zones used to protect wetlands may not be sufficient to promote amphibian biodiversity, as they do not include an area of natural surrounding vegetation; a buffer zone of 159 m - 290 m has been recommended as a suitable distance (Semlitsch and Bodie 2003). Wetland areas in North Eastern KwaZulu-Natal were mapped using Geographic Information Systems, and buffer zones of 290 m, 159 m, 100 m, 50 m, 30 m, and 20 m were applied to determine degree of connectivity for management recommendations. Wetlands that were connected by these buffer zones were regarded as a single conglomerate. The buffer zone areas within each of these conglomerates were measured and percentage of the total study area that was occupied by each buffer zone calculated. The 290 m buffer zone connected all the wetlands within this study area while the 20 m buffer zone did not. The application of a 290 m and 159 m buffer zone on a conglomerate of wetlands connected by a 100 m buffer seemed most feasible management recommendation. The latter incorporated a percentage of the total study (6.4% and 4.3%) area similar to the percentage occupied by the recommended 20 m

buffer zone (5.5%) around all wetlands, and still incorporated the range under protection put forward by Semlitsch and Bodie (2003).

Introduction

The value of wetlands for the maintenance of fresh water systems has been recognised (Kotze 1996). During the early 1900's wetlands were regarded as wasteland, and it was common practice to drain and cultivate them. Subsequently, the role of wetlands in filtering and regulating fresh water systems has been documented; and standards have been introduced that promote their conservation (Cowan 1995). These standards are based on conserving the functioning of a wetland, but do not take into account the biodiversity that is associated with that ecosystem. Studies have shown that the terrestrial habitat adjacent to wetlands supports many wetland-dependent species, and that conservation of the wetland area alone is insufficient in maintaining the biodiversity of a wetland ecosystem (Findlay & Houlahan 1997; Semlitsch 1998; Calhoun & Klemens 2002; Semlitsch & Bodie 2003; Harper, Rittenhouse & Semlitsch 2008).

Semlitsch and Bodie (2003) determined the core habitat size needed for the maintenance of the life histories of semiaquatic amphibians (32 species) in North America to be between 159 m and 290 m from the edge of the aquatic system. In South Africa, cultivation through, and within 10 m of the edge of a wetland is prohibited (Conservation of Agricultural Resources Act 43 of 1983; Brenchley et al. undated public handout). In regions under forestry, a buffer of at least 20 m from the edge of the wetland is suggested. Research was undertaken to provide guidelines for buffer zone delineation and degree of connectivity needed to maintain wetland functioning in plantation areas (Kotze 2004; Lindley pers. comm.). These buffer zone requirements are far less than the estimate suggested by Semlitsch and Bodie (2003) to maintain amphibian biodiversity. Their estimate was based on home range data of 32 amphibian

species, some of which have similar life histories to South African anurans. Their suggested buffer of 159 m to 290 m from the edge of the wetland encompassed various „zones of protection'. They stated that, not only is a buffer zone needed around the wetland itself, but there needs to be an area of core habitat that is also protected. It is this core habitat that most amphibians inhabit, whilst they use the wetland area mainly for breeding (Semlitsch & Jensen 2001; Semlitsch and Bodie 2003; Harper et al. 2008). The previous study (Chapter 2) found the species richness of amphibians in sugar cane and gum plantations to be significantly less than in conservation areas in the same region in South Africa, and highlighted the lack of suitable habitat in these land use types as a contributing factor to this difference. It may be that the minimum buffer zone requirements for wetlands of 10 or 20 m, while they maintain wetland functioning, are unable to maintain amphibian biodiversity. The distributions of South African amphibians were published in the Atlas and Red Data Book of the Frogs of South Africa (2004), and to date there is little or no reliable data on the home ranges of South African frogs. It would thereby, be impossible to calculate the core habitat requirements of South African frogs using the method outlined by Semlitsch and Bodie (2003), though from their findings and the research of others, it would seem important that this be done (Findlay & Houlahan 1997; Semlitsch 1998; Semlitsch & Jenson 2001; Calhoun & Klemens 2002; Semlitsch & Bodie 2003; Harper, Rittenhouse & Semlitsch 2008). This study explored the potential and viability of using Semlitsch and Bodie's (2003) buffer zone estimate, whilst taking into account the extent of connectivity between wetlands to assist in selecting which wetlands have the greatest conservation potential, with an aim of conserving not only the functioning of a wetland system, but also it's biodiversity. In particular, wetland areas in North Eastern KwaZulu-Natal were mapped using Geographic Information Systems, and buffer zones of 290 m, 159 m,100 m, 50 m, 30 m, and 20 m were used to determine degree of connectivity for management recommendations.

Methods

Study Area

A desktop study was conducted using Geographic Information System (GIS) software ARCVIEW 3.2a (Environment System Research Institute Inc. (ESRI), Redlands, California). Aerial photographs and spatial data of the study region were obtained from the KwaZulu-Natal Department of Agriculture. As the full study region covered an area of over 6000 km^2, a sample study area was selected. The selection criteria used were that the area must be either under sugar cane cultivation or gum plantation, and must contain wetland areas. Wetland area spatial data, land use data and the aerial photographs (KwaZulu-Natal Department of Agriculture) were overlaid and compared with satellite imagery from Google Earth. The selected study area was between 32.34°S 28.18°E in the north western corner, 32.40°S 28.18°E in the north east corner, 32.34°S 28.26°E in the south west corner, and 32.40°S 28.26°E in the south east corner. It has a total area of 5438.69 ha. It was situated approximately mid-way between Matubatuba and Hluhluwe, with the western shore of iSimangaliso Wetlands Park bordering it in the East (Fig 3.1). The area is mostly covered by sugar cane, with some areas under gum plantation, and a small proportion left fallow.

Mapping and area calculation

Within the study area wetlands were identified and digitally mapped (Fig 3.2). A change in colour and vegetation type indicates the possible edge of a wetland. Exact delineation of a wetland area requires extensive field work and the examination of the soil profile, but it is generally accepted that an estimation can be made from an aerial photograph (Department of Water Affairs and Forestry). This study is exploring a way of identifying wetlands that can be connected by a buffer zone area, and therefore delineating the exact edge of wetlands may not

be necessary. Around each of the mapped wetlands, buffer zones of the following distances were added: 290 m, 159 m, 100 m, 50 m, 30 m, and 20 m; using the „CREATE BUFFERS' tool in ARCVIEW 3.2a. This range of buffer distances hoped to encompass were the range suggested by the study done by Semlitsch and Bodie (2003), the minimum distance suggested for regions under forestry, and a range of distances in-between. For each of these buffer zone distances, the wetlands that were not close enough to each other to be connected by the buffer zone were excluded. The largest group of connected wetlands was identified and manually selected by producing a new attributes table and using this to create a shape file. This produced a different conglomerate of wetlands for each buffer zone distance. On each of the conglomerates produced, the buffer zone distances of 290 m, 159 m, 100 m, 50 m, 30 m and 20 m were applied. The areas of each of these buffer zones were calculated using the XTOOLS extension. These area values were combined in a table and the percentage they represented of the total study area was calculated. These percentages represent the relative amount of land that would be removed from potential cultivation if that buffer zone were put in place, and allows for a comparison of the economic implications of each of these buffer zones.

Results

The 290 m buffer, which was applied to the wetlands within the study area, connected all wetlands in a single conglomerate (Fig 3.3). The 159 m, 100 m, 50 m, and 30 m buffer zones formed smaller conglomerates of connected wetlands around a central group (Fig 3.3 and 3.4). The 20 m buffer applied to all the wetlands in the study area did not connect any wetlands to each other (Fig 3.3). The area occupied by the conglomerate formed by the 50 m and the 30 m buffer was almost the same (Fig 3.3).

The 290 m buffer of the 290 m conglomerate occupies 36.6% of the total study area, the areas occupied by the 159 m, 100 m, 50 m, 30 m and 20 m buffer of the 290 m conglomerate

were 23.2%, 16.0%, 9.4%, 6.8% and 5.5% of the total study area, respectively (Fig 3.5). For the smaller conglomerates the differences in percentage of the total area between each of the buffer zones decreased. For the 159 m conglomerate the 290 m buffer occupied 9.1% of the total study area, the 20 m buffer occupied 1.6%. The 290 m and 159 m buffer of the 100 m conglomerate covered 6.4% and 4.3% respectively. The 20 m buffer of the 100 m conglomerate was 1.2%. The percentage areas covering the total study area of the 50 m and the 30 m conglomerate were very similar. The 290 m, 159 m, 100 m, 50 m, 30 m and 20 m buffers of the 50 m conglomerate were 3.5%, 2.1%, 1.6%, 1.0%, 0.8% and 0.6%, respectively. The 290 m, 159 m, 100 m, 50 m, 30 m and 20 m buffers of the 30 m conglomerate were 3.4%, 2.1%, 1.5%, 1.0%, 0.7% and 0.6%, respectively (Fig 3.5).

From all the percentage values of the areas that the buffer zones cover, six values fell between 6.9% and 4.1%; those were the 30 m buffer of the 290 m conglomerate at 6.8%; the 20 m buffer of the 290 m conglomerate at 5.5%; the 159 m and 100 m buffers of the 159 m conglomerate at 6.5% and 4.7%; and the 290 m and 159 m buffer of the 100 m conglomerate at 6.4% and 4.3% respectively. These buffer zones occupied a similar proportion of the total study area, but the spatial density of this value differed, as can be seen in Figure 3.6 where the 20 m buffer of the 290 m conglomerate (20 m buffer around all the wetlands) and the 290 m and 159 m buffers of the 100 m conglomerate are highlighted.

Discussion

There has been mounting evidence that the buffer zones used to protect wetlands do not conserve amphibian biodiversity (Findlay & Houlahan 1997; Semlitsch 1998; Semlitsch & Jensen 2001; Calhoun & Klemens 2002; Semlitsch & Bodie 2003; Harper, Rittenhouse & Semlitsch 2008). The intrusive and destructive nature of sugar cane (*Saccharum officinarum*) farming (where the sugar cane is burnt after one year's growth, and cut after the second year)

and less-so of forestry (once the trees are clear-felled the land is burnt, but the interval between this is 8-30 years) seems to affect the biodiversity of amphibian species in these areas (see results of the previous study, Chapter 2). Karraker and Welsh (2006) found that clear-cutting (the method that is employed in South Africa) in forestry areas affected the species richness of amphibians for up to 25 years later. Todd and Rothermel (2006) also found that clear-cutting significantly reduced the number of southern toads (*Bufo terrestris*). These studies and others suggest that in order to conserve amphibians within these land use types an area of natural habitat be left as a refuge for species. Semlitsch and Bodie (2003) have suggested a 159 m to 290 m buffer zone around all wetlands that encompasses a region of core habitat. Within the example from this study, various ways this buffer zone could be incorporated have been explored.

The 290 m buffer, the upper value of the range suggested by Semlitsch and Bodie (2003), applied to all wetlands connected them in a single conglomerate whilst the 20 m buffer, that is suggested for regions under forestry, when applied to all wetlands did not connect any of them (Fig 3.3 and 3.4). The value of connectivity between breeding sites and the variation in habitat within this area has come to be recognised as an important factor in the conservation of amphibians, if a breeding site is small and becomes isolated within an inhospitable environment then it's extinction rate will be higher (Fahrig & Merriam 1985; Semlitsch & Bodie 1998; Kirkman et al. 1999; Fahrig 2001; Werner et al. 2007).

The 36.6% occupied by the 290 m buffer around all the wetlands (ie: of the 290 m conglomerate) is the relative amount of total study area that would be set aside for conservation should that buffer zone be applied. This 36.6% is representative of the amount of land that would no longer be available to cultivation (Fig 3.3 and 3.5). It is unlikely that a landowner would set aside 36.6% of their land for conservation purposes. What is interesting to note is that in the example used in this study, the 20 m buffer (which is the current buffer zone recommended for

forestry regions) around all the wetlands sites amounts to 5.5% of the total study area, and this value is similar to the 6.4% and 4.3% of the 290 m and 159 m buffer of the 100 m conglomerate, respectively. Using this, a landowner could set aside the land that falls within the 290 m and 159 m buffer zones of the 100 m conglomerate and have a similar percentage of land „lost' to conservation as the 20 m buffer zone around all wetlands (Fig 3.6). Applying the 290 m and 159 m buffers on the 100 m conglomerate also allowed for the conservation of an area that fell within the range of the buffer zones suggested by Semlitsch and Bodie (2003). The application of these buffer zones may potentially facilitate the conservation of amphibian species, and protect the functioning of the wetland system. Similarly, if a landowner decided that the conservation of 6.4% of his land was still too high (as a 10-20 m buffer zone around all wetlands is a mandatory practice), the 290 m and 159 m buffer zones of the 50 m conglomerate or the 30 m conglomerate could be applied where 3.5% and 3.4% of the total area would be conserved and still incorporate the range of buffer zones suggested by Semlitsch and Bodie (2003) (Fig 3.3 and 3.5).

This desktop study that has been conducted merely explored some of the possibilities of using a range of buffer zones that could encompass some core habitat for the conservation of amphibians. The possibilities for further research in the area are numerous. The same or similar application of buffer zones and their use to identify connected wetlands may be applied in a different area, and the feasibility of applying them in the field studied. The effects of the different buffer zones of different wetland conglomerates on amphibian biodiversity could be investigated. This study does also highlight the need to determine the home ranges of South African frog species, and to further examine the buffer zone recommendations and legislation regarding wetland protection.

Conclusion

This study can be regarded as a pilot study into the possibility of applying the range of buffer zones suggested by Semlitsch and Bodie (2003), to promote the conservation of amphibians. The application of the suggested 290 m and 159 m buffer zone on a conglomerate of wetlands connected by a 100 m buffer, in this example seemed most feasible as it incorporated a percentage of the total study area similar to the percentage occupied by the recommended 20 m buffer zone around all wetlands, and still incorporated the range under protection put forward by Semlitsch and Bodie (2003). This study opens the field for a more detailed look into the value of the buffer zones used for wetland conservation in South Africa.

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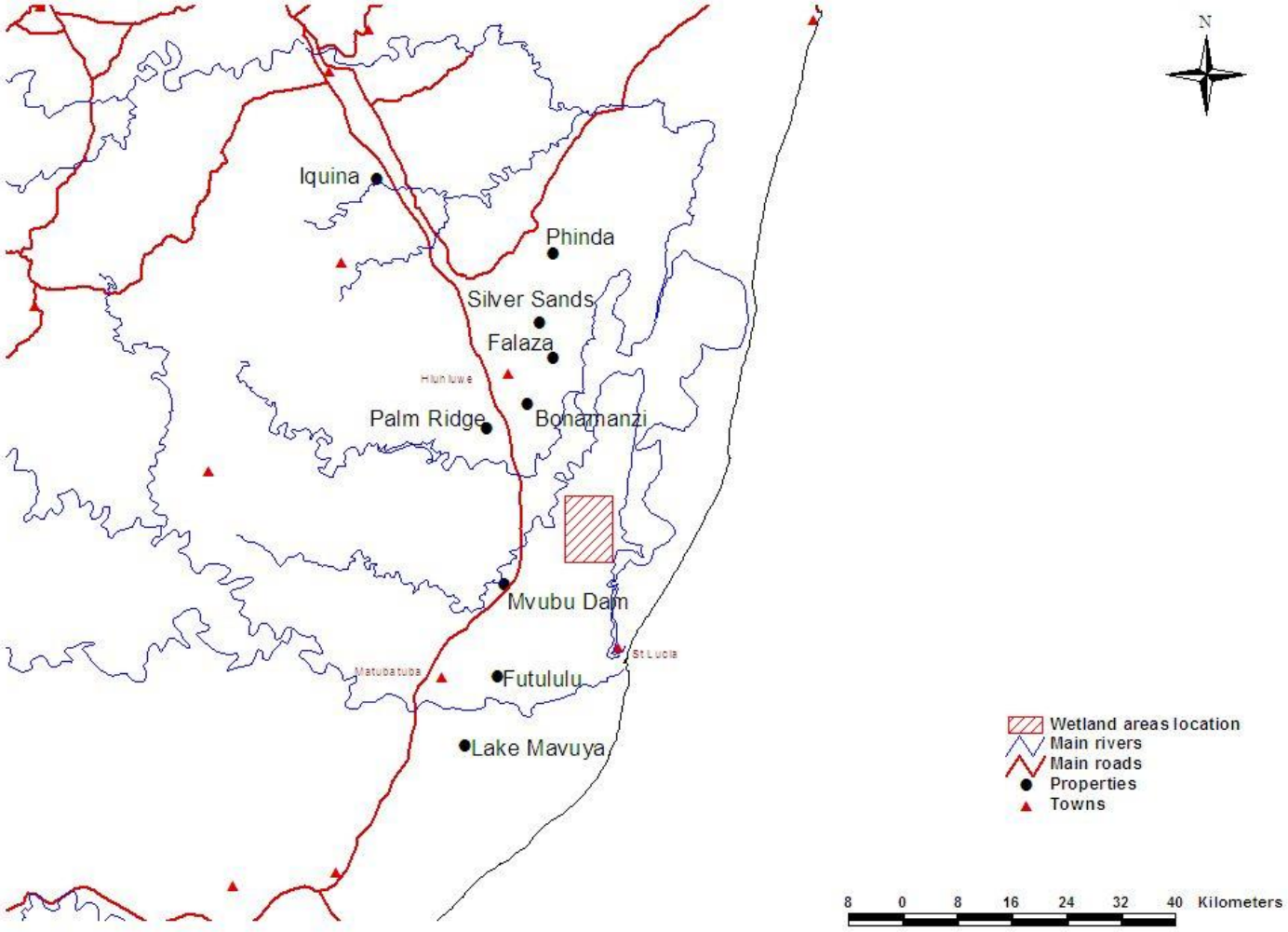

Figure 3.1 Location of study area, in Northern KwaZulu-Natal, South Africa.

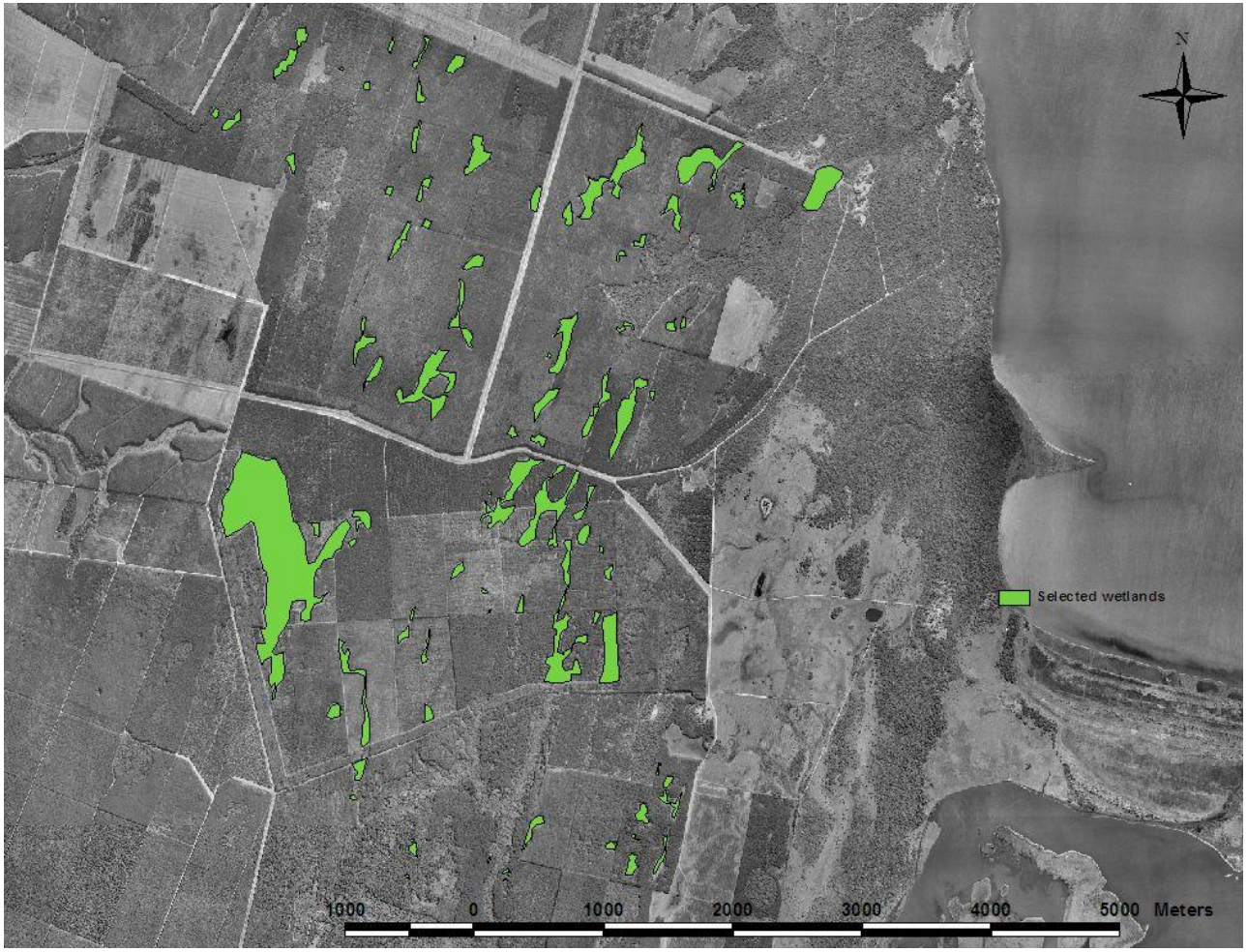

Figure 3.2 Aerial photograph of the study area and the wetlands used for the buffer. zone calculations

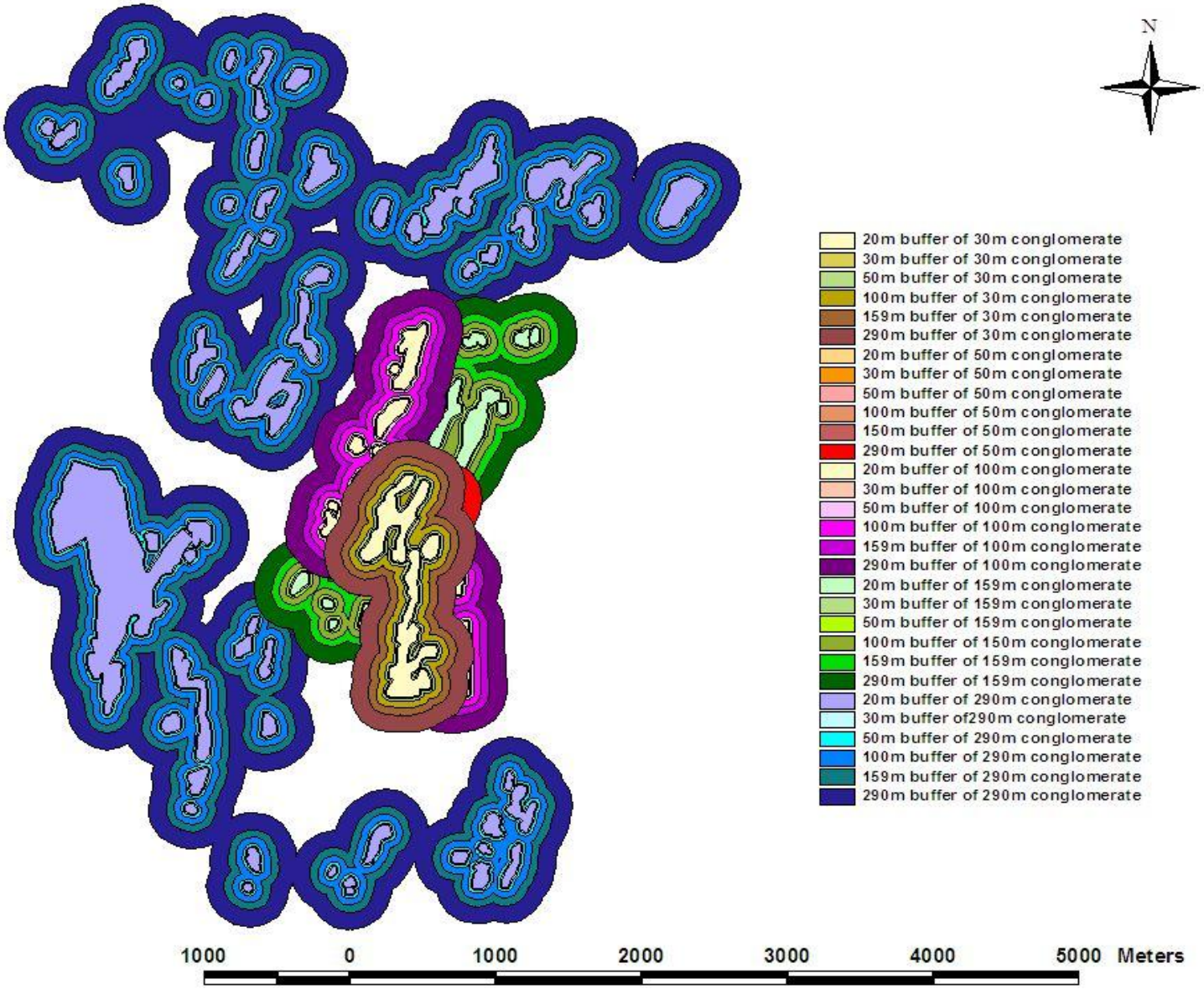

Figure 3.3 Wetland conglomerates in their spatial setting.

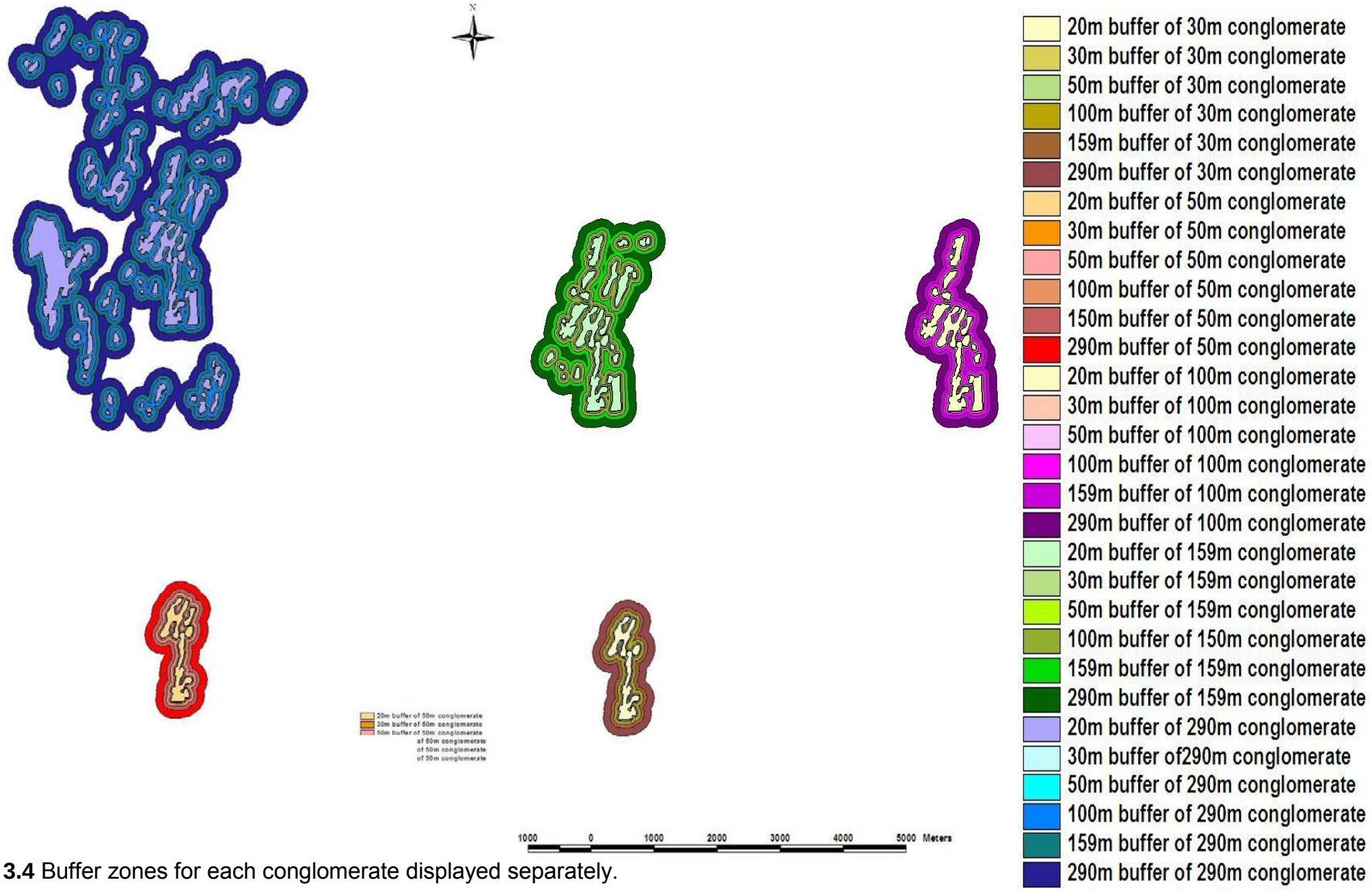

Figure 3.4 Buffer zones for each conglomerate displayed separately.

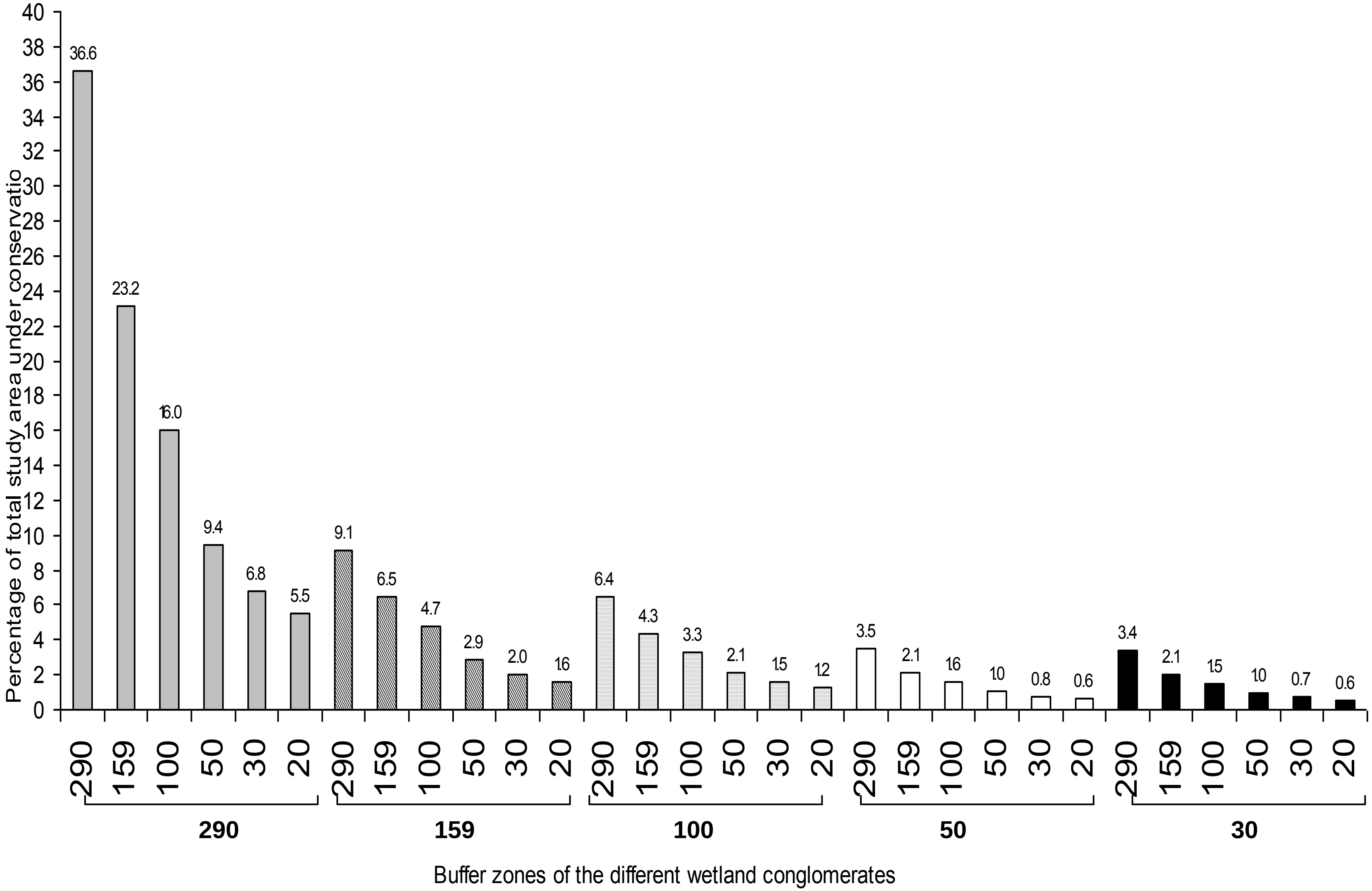

Figure 3.5 Buffer zone distances (m) of the different wetland conglomerates (290 m, 159 m, 100 m, 50 m, 30 m) as a percentage of the total area that would be available for cultivation.

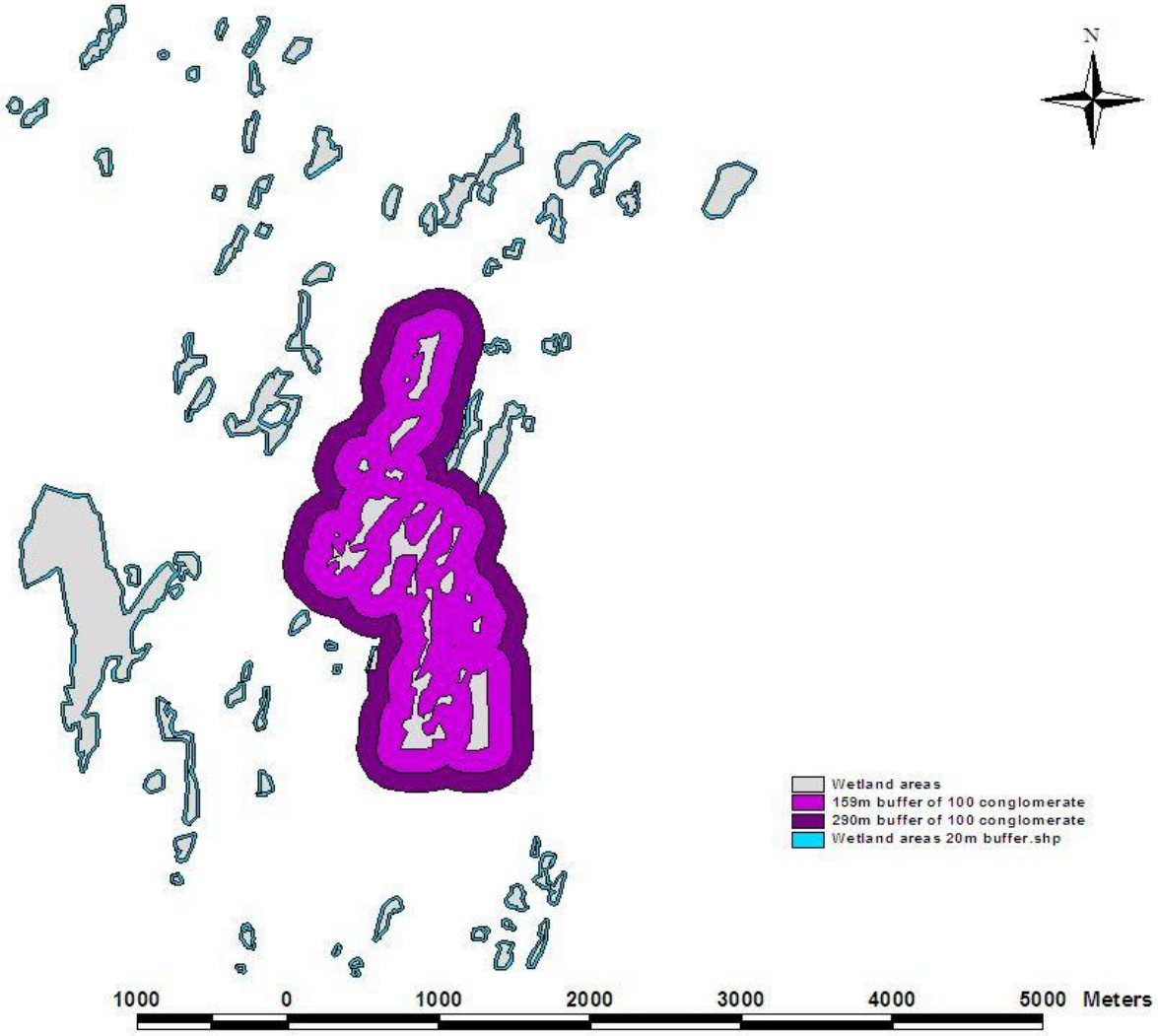

Figure 3.6 Areas of 20m buffer (around all wetlands), and the 290 m and 159m buffer of the 100m conglomerate

Chapter 4

Conclusions and implications for management

Amphibian declines and land use

Global amphibian declines have been attributed to various factors, global climate change, increase in ultra violet radiation, toxic chemicals, increased pollution, disease, and habitat loss and fragmentation (Alford & Richards 1999; Blaustein & Kieseker 2002; Behangana & Arusi 2004; Griffiths 2010) (Chapter 1). Of these, habitat loss and fragmentation is one of the biggest threats faced by South African amphibians (Branch & Harrison 2004; du Preez & Carruthers 2009). Human population has increased substantially over the last 100 years. Demand for space for human settlement, agricultural production and industry has placed natural areas under threat. Habitat loss and fragmentation has threatened amphibian species diversity and richness (Fahrig & Merriam 1994; Vitousek et al. 1997; Fahrig 1998; Fahrig 2001; Pineda & Halffter 2004; Beebee & Griffiths 2005; du Preez & Carruthers 2009; Griffiths et al. 2010) (Chapter 1). Amphibian species are susceptible to changes in their environment, and can be used as indicators of environmental stress (Beebee 1996). Different land use types may have different effects on the environment due to different management practices (Kotze 2004), and subsequently may affect frog species in different ways (Chapter 1 and 2).This study found that species composition (which species are present or absent) may be used to indicate where problems lie within a landscape (Chapter 2) Identifying what species are present on a property can comparing them to which are missing but should be there can give an indication of where an ecological problem might lie (Chapter 2). To enable long-term monitoring, the number of individuals within a population would have to be assessed (Chapter 2).

Implications for Amphibian species in South Africa

South Africa is a developing country growing at an ever-increasing rate, and this is placing pressure on natural systems (Kotze 2004) (Chapter 1). This study showed that land use had a negative effect on the species composition of amphibians, there were less species found on the sugar cane (*Saccharum officinarum*) and gum (*Eucalyptus* sp.) plantation sites (Chapter 2). Wetlands and grassland/woodland complexes were not represented within these land use types. The species that were not found in the gum and sugar cane plantations were those that were completely dependent on open water bodies, and those that were not dependent on water bodies (Chapter 2). These forms of land use type are disruptive (Kotze 2004), and have removed the natural vegetation (grassland and woodlands). The habitat that is available within sugar and gum plantations does not support as wide a range of species as the conservation areas do (Chapter 2).

To mitigate some of the effects of these agricultural practices, buffer zones of 10-20 m are recommended and applied around all wetlands (Brenchley et al. undated public handout) (Chapter 3). These distances protect the functioning of the wetland, but may not promote the conservation of amphibian species (Semlitsch 1998) (Chapter 1 and 3). A study conducted in North America took into account the home ranges of the local amphibian species and found that a buffer zone of 159 m to 290 m would incorporate enough natural vegetation surrounding a wetland to support those species (Semlitsch and Bodie 2003) (Chapters 1, 2, & 3). These buffer zone distances and a range of others were applied to numerous wetlands within a sample study area. The 290 m buffer zone connected all the wetlands, but occupied 36.6% of the total area available for cultivation, while the 20 m buffer zone did not connect any of the wetlands. The study found that the most feasible buffer zone distances were likely to be the 290 m and 159 m distance applied around the wetlands

connected with the 100 m buffer (the 100m conglomerate); as this incorporates the range of buffer zones recommended by Semlitsch and Bodie (2003); and occupies a similar percentage of the total area as the 20m buffer zone (Chapter 3).

The buffer zone recommendations and methods of wetland delineation are currently being revised by the Mondi Wetlands Project (Kotze 2004; Lindley pers. comm). The focus of buffer zone use needs to incorporate the aspects of the landscape as a whole if conserving the biodiversity of an area is a priority. How wetlands connect to each other, and the condition of the connecting habitats has to be considered (Kirkman et al. 1999; Werner et al. 2007) (Chapter 3). A high species diversity of frogs is usually a reflection of a healthy environment (Welsh & Ollivier 1998) and management practices that aim to promote this should ensure the protection of the whole ecosystem (Chapter 2).

Opportunities for future research

Research on amphibians in South Africa has centred around genetics, taxonomy, and more recently the spread of the chytid fungus *Batrachochytrium dendrobatidis*, which has been investigated as a contributor to global amphibian declines. This study highlighted the need for research into the home ranges of South African frogs (Chapter 3). The desktop study that was conducted merely explored some of the possibilities of using a range of buffer zones that could encompass some core habitat for the conservation of amphibians (Chapter 3). The possibilities for further research in the area are numerous. The same or similar application of buffer zones and their use to identify connected wetlands may be applied in a different area, and the feasibility of applying them in the field could be studied. The effects of the different buffer zones of different wetland conglomerates on amphibian biodiversity could also be investigated.

The use of amphibian species composition as an indicator of the environmental condition of an area could also be explored further. To date the effect of chemical pollution on tadpoles has been researched in South Africa (Channing 1997), but a wider study taking into account water quality data, species richness and population density may prove to be valuable. Amphibian species composition was found to be a useful bio-indicator tool (Chapter 2). When only tadpole or water dependent species are studied, they represent only part of the landscape. Investigating all possible species within an area may indicate where an environmental problem may be situated. This is a concept that needs further study (Chapter 2).

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