Snake population declines and conservation – A global synthesis, and perspectives from southern Africa, based on long-term field observations

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Submitted in fulfilment of the academic requirements for the degree of

Master of Science

In the Discipline of Ecological Sciences

School of Life Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg Campus

2018

UNIVERSITY OF KWAZULU-NATAL

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ABSTRACT

Amphibian and reptile declines have been documented from across the globe in recent decades. This is a result of anthropogenically driven effects including transformation of the landscape, habitat destruction, environmental degradation, road mortality, leaching of chemicals and pollutants into the environment, genetic isolation and disease. More recently, several well-studied declines affecting snakes have been documented in the literature. Most studies emanate from North America and Europe, with a small percentage from Australia. Due to the absence of long-term site monitoring in Africa, the extent of snake population declines is mostly unknown and at best, speculative.

My study aimed to provide baseline data on snakes from South Africa based on long-term field observation and accumulative data spanning a period of approximately 30 years, from 1988 – 2018. In my experience, I have noted perceived declines in several geographical regions, including species-specific declines. Whilst the primary focus of this study was on snakes, these declines extend to other amphibian and reptile species, and brief reference is made to these in the specific site studies.

Firstly, in Chapter 1, I reviewed the published literature globally pertaining to snake conservation, population ecology and documented snake population declines and the contributing factors thereof. The causes of decline are complex and often interlinked, having a cascading effect. For example, a population of snakes isolated by roads and urban development will become genetically isolated, leading to weakened immunity and increased stresses, making them susceptible to disease and overloaded parasite burdens. Therefore, a population experiencing declines is affected by several interlinking causes. All contributing factors must be carefully analysed to initiate mitigation measures to prevent further decline.

Secondly, in Chapter 2, I reviewed our current understanding of global snake diversity, conservation and systematics to quantify species diversity and conservation trends in extant snake species. We are far from understanding true snake species diversity with numerous new species being described by science annually. Systematics and taxonomy, including phylogenetic relatedness, are all crucial aspects required to facilitate and implement effective conservation measures if we are to conserve world snake diversity.

Thirdly, in Chapter 3, I have presented snake data pertaining to road mortality based on a study undertaken along the R516 national road in Limpopo Province, South Africa. Road mortality has been identified as a contributing factor of snake population declines in many regions of the globe. The increasing network of roads and associated vehicular traffic is cause for concern, not only in protecting snakes, but other faunal species as well.

In Chapters 4 and 5, I examined data from personal archived records taken at two different, well-defined, field study sites – one site situated in a former grassland habitat in Gauteng Province, which is now completely transformed, and a second site on the lower South Coast of KwaZulu-Natal Province, which has experienced relatively lower rates of anthropogenic habitat transformation. Both sites have been randomly surveyed for a period spanning approximately 30 years and may represent two of the longest-running site specific herpetological surveys undertaken in southern Africa. The impact of anthropogenic habitat transformation through ecological succession and urban development on species populations and diversity is discussed in detail. In the absence of consistent, methodologically robust surveys using trap arrays and mark-recapture studies, which are absent in South Africa, long-term field observation may be the only available option in identifying possible snake declines. This sentiment is echoed elsewhere across the globe where numerous seasoned herpetologists have indicated that snakes have declined in their respective field sites in recent decades. My data support this.

In Chapter 6, I selected a common, widely distributed snake species, the rinkhals (*Hemachatus haemachatus*), as a species-specific candidate. These elapid snakes appear to have experienced dramatic declines in some parts of their range, i.e. the Western Cape and eastern Zimbabwe, but which are still thriving within a peri-urban environment on the eastern highveld in Gauteng. Factors contributing to its success or decline are discussed.

In conclusion, our current lack of long-term monitoring is highlighted, as well as challenges and possible solutions and methods to gain better insight and understanding of snake population declines regionally and globally. The pros and cons of utilizing citizen science, virtual museums and social media data sets is discussed within the context of providing skewed data that may mask underlying population trends, providing a biased output which may in turn affect accurate conservation assessments. This thesis aims to be a qualitative study rather than a quantitative analysis. However, various population and ecological models are being researched for further statistical testing.

PREFACE

All data used in this thesis, unless otherwise stated, were collected over a period spanning approximately 30 years by Warren R. Schmidt. A proposal to undertake a Master of Science degree was submitted and accepted by the University of KwaZulu-Natal. The project has been managed under the supervision of Professor Colleen T. Downs.

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

……..

Warren R. Schmidt

December 2018

I certify that the above statement is correct and as the candidate's supervisor I have approved this thesis for submission.

……

Professor Colleen T. Downs

Supervisor

December 2018

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DECLARATION 1 – PLAGIARISM

I, Warren Robert Schmidt, 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.
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DECLARATION 2 – PUBLICATIONS

Details of contributions to publications that form part and/or include research presented in this thesis.

Publication 1

Schmidt, W. R. & Downs, C. T. Snake population declines – a global review.

WRS conceived paper with CTD. WRS collected and reviewed the literature and wrote the paper. CTD contributed comments to the manuscript.

Publication 2

Schmidt, W. R. & Downs, C. T. Global snake diversity, systematics and conservation: a review.

WRS conceived paper with CTD. WRS collected and analysed data and wrote the paper. CTD contributed comments to the manuscript.

Publication 3

Schmidt, W. R. & Downs, C. T. Snakes on roads – a case-study in the Savanna Biome of Limpopo Province, South Africa.

WRS conceived paper with CTD. WRS collected and collated data and wrote the paper. CTD contributed comments to the manuscript.

Publication 4

Schmidt, W. R. & Downs, C. T. Changing landscape – the herpetofauna of a former grassland habitat, with reference to snake diversity and adaptability to urban transformation.

WRS conceived paper with CTD. WRS collected and analysed data and wrote the paper. CTD contributed comments to the manuscript.

Publication 5

Schmidt, W. R. & Downs, C. T. Herpetofauna on the South Coast of KwaZulu-Natal: composition and declines.

WRS conceived paper with CTD. WRS collected and analysed data and wrote the paper. CTD contributed comments to the manuscript.

Publication 6

Schmidt, W. R., Prinsloo, C. & Downs, C. T. Peri-urban rinkhals *Hemachatus haemachatus* (Reptilia: Squamata) in Gauteng: adapting to a changing landscape.

WRS conceived paper with CTD. WRS and CP collected data. WRS wrote the paper. CTD and CP contributed comments to the manuscript.

Warren R. Schmidt

December 2018

ACKNOWLEDGEMENTS

Numerous friends, associates and colleagues, some since passed, have assisted me in many ways over the preceding 30 years. They are too numerous to mention here; however, they will be acknowledged individually in a summary publication planned for 2019. This thesis is a tribute to your individual friendships, insights and contributions, both in the field and passing on of knowledge, books, publications and more. I'm honoured to have been part of the South African herpetological and conservation community for the better part of three decades.

Specifically, for this thesis, I would like to acknowledge the School of Life Sciences at the University of KwaZulu-Natal (UKZN), Pietermaritzburg campus, and especially Professor Colleen T. Downs for taking on this project and assisting with the initial conceptualising and planning of the thesis. Her faith in a long-distance, middle-aged student is truly humbling.

Tanya Karalic and Professor Kevin Kirkman are thanked for ironing out administration and registration issues. Sue McConnachie is thanked for assistance with my initial enquiries. Cormac Price and Preshnee Singh are acknowledged for insightful discussions whilst at UKZN. Dr Bryan Maritz is thanked for originally bringing my attention to global snake population declines and stimulating a fascinating research foray into snake ecology and population dynamics. Kay Montgomery is truly thanked for all her assistance over the years and firmly believing in and motivating me to register for this degree. Luke Verbugt of Enviro-Insight is thanked for his assistance in GIS mapping. Jens Reissig is thanked for his logistical support and friendship over several years and for assisting me in many ways. My parents, Robert and Audrey Schmidt, and brothers Anthony, Dean and Justin, are acknowledged for all they have done. I couldn't have asked for more. And most importantly, I would like to acknowledge my wife and daughter, Nicolette and Hannah, for their patience, unconditional love, understanding and support during this academic adventure.

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CHAPTER 1: INTRODUCTION

Snake population declines – a global review

1.1 ABSTRACT

Vertebrate population declines are generally well-documented in the scientific literature. However, understanding of causal factors contributing to declines vary greatly between taxonomic groups. Traditionally, mammals and birds have received relatively greater attention compared with amphibians and reptiles. The rapid global decline in amphibian populations stimulated unprecedented research interest into amphibian biology and conservation over the last three decades. Recently, population declines are acknowledged to be affecting a full spectrum of vertebrates and invertebrates across many taxa, including snakes. We review current literature related to snake population declines and summarize the trends, main drivers of decline and conservation efforts. In conclusion, we find that snakes, along with other documented species declines, are not immune from the same trends. Declines are often complex and factors contributing to declines are often interlinked.

Keywords

Snake population declines; global review; species diversity; conservation; environmental change; habitat fragmentation, destruction and degradation; climate change; agri-industrial chemicals; fire; road mortality; pathogens, alien invasive species; trade.

1.2 INTRODUCTION

Global biodiversity loss through anthropogenic change on ecosystems and habitats is well documented across many taxonomic groups (Osborne et al., 1999; Craigie et al., 2010; WWF Living Planet Report, 2014). The causal factors leading to species declines are often multi-

faceted and our understanding of the contributing factors leading to a species decline varies considerably between different taxonomic units (Gibbons et al., 2000; Reading et al., 2010). Traditionally, mammals and birds have received relatively greater attention compared with amphibians and reptiles. Recently, population declines are acknowledged to be affecting a full spectrum of vertebrates and invertebrates across many taxa (Roll et al., 2017). There is now mounting evidence to suggest that reptiles, including snakes, are indeed declining (Gibbons et al., 2000; Reading et al., 2010). Factors contributing to reptile declines are often multi-faceted or inter-linked, and include habitat loss and degradation, introduced invasive species, environmental pollution, disease, unsustainable use, and global climate change (Gibbons et al., 2000). Rapid global declines in amphibian populations have stimulated unprecedented research interest into amphibian biology and conservation over the last three decades (Beebee, 1992; Alford et al., 1999). Amphibians are not necessarily at higher risk compared with reptiles and other vertebrates such as fishes (Beebee, 2009).

We reviewed the current literature related to snake population declines and summarized the trends, main drivers of decline and conservation efforts. These drivers include habitat destruction and fragmentation, environmental degradation, road mortality, fire, ecological succession, climate change, chemical pollutants and toxins, disease and pathogens, invasive alien species and trade and exploitation. As for amphibians, we predicted that the major factors causing declines in snake populations were mainly anthropogenically induced including habitat change, habitat loss, trade, pollution, climate change and disease.

1.3 TAXONOMY

Snakes are a highly diverse group of squamate reptiles with approximately 3 750 species described to date (Uetz et al., 2018). Snakes are found across all continents and many oceanic islands, from below sea level (elapid sea snakes) to almost 5 000 m altitude in the Himalayan

Mountains (e.g. *Gloydius himalayanus*) (Mattison, 1995). They have adapted to a range of habitats, from sandy deserts to tropical rainforest (Greene, 1997). As ectotherms, the greatest diversity is found in the tropics (Brazil alone has 330+ species), however, the European Viper (*Vipera berus*) is found within the Arctic circle in Scandinavia at a latitude of 69°N (Mattison, 1995). One genus, *Thermophis*, survives in the high-altitude Tibetan Plateau at altitudes between 3 362 m at Shangri-La to 4 891 m at Yukchong by utilising geothermal hot-springs (Peng et al., 2014).

True snake species diversity has yet to be recognized with no less than 591 species having been described post-2000 (Uetz et al., 2018). This excludes the numerous subspecies recognised as taxonomic entities. Recent studies incorporating gene sequencing have revealed numerous cryptic species which have yet to be formally described (Bates et al., 2018). Higher taxonomy used in this paper follows that of Figueroa et al. (2016). Each consecutive phylogenetic study, while in many circumstances reaching a broad consensus, may differ in topology. For a review and discussion of recent snake phylogenies and the different outcomes, see Streicher and Wiens (2016).

Furthermore, many previous subspecies of snake have been more recently elevated to species rank, for example, *Pantherophis obsoleta* (Burbrink, 2001); *Psammophis sp.* (Broadley, 2002); *Naja annulifera* (Broadley and Wüster, 2004); *Lampropeltis getula* (Pyron & Burbrink, 2009), to name a few. Burbrink (2001) stated: "Unless subspecies are found to be true species, then they have no real taxonomic meaning with respect to distinct evolutionary lineages." However, despite the argument above whilst the general taxonomic trend is to move away from the traditional recognition of subspecies, some authors still argue for the retention of subspecific names under certain circumstances (see Hawlitschek et al., 2012 for details).

The placement of several snake genera within families or subfamilies is still not resolved (Figueroa et al., 2016; Streicher & Wiens, 2016). Several genera are still viewed as

incertae sedis such as *Thermophis* (considered a dipsadine by some authors) and *Buhoma*, *Psammodynastes* and *Oxyrhabdium*, considered lamprophiines, but cannot be confidently placed within any of the existing subfamilies (Streicher & Wiens, 2016). Likewise, *Micrelaps* and *Homoroselaps* are often placed within the Atractaspididae, but phylogenetic studies have shown them to be outside of these clades (Streicher & Wiens, 2017). For conciseness in this review, these *incertae sedis* genera are placed within the nominotypical subfamily, i.e. Colubrinae for *Thermophis*, Lamprophiinae for *Buhoma*, *Psammodynastes* and *Oxyrhabdium* and Atractaspididae for *Micrelaps* and *Homoroselaps* pending further research outcomes. For further details, see Pyron et al., (2010; 2013), Kelly et al., (2011) and Figueroa et al., (2016).

1.4 GLOBAL REVIEW

The following section reviews current knowledge on snake conservation in relation to population trends and declines and the associated contributing factors thereof. An extensive global review of the literature is discussed, with relevant papers placed subjectively.

1.4.1 Population trends

Among the vertebrates, snakes are one of the most challenging to assess accurately for population declines (Reading et al., 2010). Their often secretive and cryptic nature make them difficult subjects to monitor and there are few long-term population studies – mostly restricted to North America, Europe and Australia (Matthews et al., 2002; Weatherhead et al., 2002; Beebee et al., 2009). Radio telemetry is commonly used to track snake activity, and therefore field studies are often conducted on larger snake species such as pythons (Pythonidae), boas (Boidae), and to a lesser extent, the larger elapids (Elapidae) and viperids (Viperidae) (Shine, 1998).

Population ecology is biased to snake species in temperate regions where distinct seasonal activity occurs, such as spring emergence from hibernacula dens, followed by mating and dispersal, which allows for easier field observation (Rudolph & Burgdorf, 1997; Godley & Moler, 2013). Snakes which form strong aggregations in restricted habitat, such as a wetland, are also easier to monitor over consecutive seasons than species with a wider habitat tolerance or foraging threshold (Roe et al., 2003). Studying snake ecology and population dynamics in the tropics is considered more challenging and assessing the conservation status accurately for many species is therefore restricted (Reading et al., 2010).

Furthermore, many regions are poorly sampled due to difficulty of access (political instability or isolation) or few resident conservation biologists with an interest in herpetology (Pianka, 2012). Therefore, surveys may be carried out sporadically by visiting scientists whereby population structure is not possible to ascertain due to sporadic and anecdotal data collection. Whilst a new locality may be plotted, the conservation status of that population may remain speculative at best (Böhm et al., 2013).

The IUCN (www.redlist.org) has assessed only 45% of described reptile species (Tingley et al., 2016). Of the ~3 750 snake species, at least 232 (6.4%) species are listed in one of the threatened categories: Critically Endangered, Endangered and Vulnerable. This figure, however, is likely to be a gross underestimate, as scientific literature includes numerous references to species assessed using IUCN criteria, but of which are not yet included in the IUCN Red List. A few examples include the recently described *Atheris matildae* from Tanzania, listed as Critically Endangered (Menegon et al., 2011); and *Bitis albanica* (Critically Endangered), *B. inornata* (Endangered), *B. armata* (Vulnerable), *Dendroaspis angusticeps* (Vulnerable) in a recent regional conservation assessment of South African reptiles (Bates et al., 2014).

However, recent initiatives, such as the Global Reptile Assessment (http://www.iucnredlistassessments.org/the-global-reptile-assessment/) have coordinated and expedited efforts across the globe to assess the conservation status of 'Data Deficient' taxa. Tingley et al. (2016) have shown that of the 4648 (out of 10400 species) that have been assessed by the IUCN, 19% (867 species) are Data Deficient. Therefore, the actual number of threatened species, and those experiencing population declines, may be much higher than currently recorded (Böhm et al., 2013). At least four snake species are listed as Extinct. These are island species and include the enigmatic *Bolyeria multocarinata* from Round Island north of Mauritius, *Typhlops cariei*, a blind snake from Mauritius, *Clelia errabunda* from Saint Lucia and *Erythrolamprus perfuscus* from Barbados (IUCN Red List). Furthermore, several species listed as Critically Endangered are presumed to be extinct. All these species were confined to oceanic islands (IUCN Red List).

It is noteworthy that of the 232 IUCN-listed threatened snakes, 101 (43.5%) are found on islands. In the Critically Endangered category, the percentage is much higher, where 47 species are listed, 33 (70.2%) are confined to islands. However, most threatened species on continental land masses are confined to 'land' islands in the form of cloud forest, mountain ranges or isolated forest mosaics, and threatened by habitat loss due to agriculture and deforestation (Böhm et al., 2013).

In a global assessment of the conservation status of the world's reptiles, Böhm et al. (2013) randomly selected 1500 reptile species and summarised extinction risk across all reptiles, including biogeographical realm and habitat systems. Incorporating these species into a statistical formula, and assuming that data deficient species would fall proportionately the same as non-data deficient species, produced a global summary highlighting which taxonomic groups were at higher risk, as well as generating a global distribution of threat processes. In terms of snakes, they calculated that up to 12% of snakes may be threatened with extinction.

Initiatives such as the Global Reptile Assessment and emphasis on reptile population declines has stimulated an increase in recent conservation assessments (Bohm et al., 2016; Maritz et al., 2016; Meng et al., 2016; Tingley et al., 2016; Tolley et al., 2016).

Additional regional conservation assessments include Fenker et al. (2014) who assessed Neotropical pitvipers (Crotalinae) based on evolutionary distinctiveness and phylogenetic diversity. Clades lacking comprehensive threat assessments, EDGE [evolutionary distinctiveness globally endangered] (evolutionary distinctiveness weighted per IUCN status) may not be a reliable measure of conservation status. EDHL Evolutionary Distinctiveness weighted per percentage of habitat loss within inferred ranges may yield more accurate results (Fenker et al., 2014). Zhou (1998) lists 209 species of snake from China (52 endemic) with 43 species of conservation concern (8 critically endangered, 9 endangered and 11 vulnerable) while Rodrigues (2005) lists 330 species of snake for Brazil with five threatened species.

1.4.2 Snake population declines

Most conservation assessments for snakes leading to a threatened category have been biased towards those with a limited extent of occurrence and associated habitat loss, because of few long-term population studies (Gibbons et al., 2000). Despite this, many researchers have raised concern over recent snake population declines, often by experienced field herpetologists who have perceived a general decline in their study subjects (Reading et al., 2010). These species are not necessarily range-restricted or rare species, but can be widespread and previously common, or common in some areas whilst in others they have experienced dramatic declines (Means, 2009; Elfes et al., 2013; Goldley & Molder, 2013).

Reading et al. (2013) combined data from consistent field surveys covering 14 snake species from Europe, Nigeria and Australia and all species demonstrated a dramatic population decline. Although surveys were carried out in selected localities, most of these species are

wide-ranging. Although no conclusions were drawn as to causal factors, and taking into consideration natural population fluctuations, the data revealed an alarming trend. A review of literature and questionnaire surveys in England has shown that reptiles are in as much trouble as amphibians (Beebee, 2009). Questionnaire surveys in England showed a major decline of *Natrix natrix* between 1970-1980 which tapered off between 1980-1990, whereas *Vipera berus* showed a gradual decline from 1970-1980 with a major decline reported between 1980-2003 (Beebee, 2009).

Snakes are susceptible to population decline because they have relatively long lives, are exclusively carnivorous and generally have low reproductive output (Santos & Llorente, 2009). *Natrix maura* in agricultural wetlands in Spain experienced a sharp decline attributed to reduction of their prey, *Pelophylax perezi*, possibly caused by bioaccumulation of organochlorine pollutants, as well as loss of habitat, increased predation by herons and road mortality (Santos & Llorente, 2009). In the United States, pygmy rattlesnakes (*Sistrurus catenatus*) have undergone rapid range contraction. Pomara et al. (2014) noted declines across the Eastern United States and Baker et al. (2016) identified sources of mortality using data collected from 2000-2011 and found that predation and road mortality accounted for 50% of observed mortalities.

However, while most snake declines are of wide-ranging and formerly common species, they should be viewed in context with the IUCN-listed species, as listed threatened species by all accounts have experienced a documented decline in range and/or population in order to have been listed. The following synopsis gives a review of literature with specific reference to snake population declines, perceived or real.

1.4.3 Enigmatic declines

Enigmatic snake declines are those occurring in protected habitats that cannot be attributed to obvious local anthropogenic disturbances (Whitfield et al., 2014). For example, Winne et al. (2007) documented the enigmatic decline of eastern king snakes (*Lampropeltis getula*) in an area free of roads and anthropogenic disturbance in South Carolina. In particular, they noted a decline of abundance in snakes as well as body condition. Snake populations were monitored over 31 years. During the first two decades, king snakes were common, but after 1996, they had virtually disappeared from the study site. Road mortality, collection, environmental pollutants all ruled out as possible declines due to the protected nature of this site and there was no direct evidence of disease. Natural succession in vegetation could have changed population dynamics. Interestingly, there was an associated increase in water moccasins (*Agkistrodon piscivorus*), possibly due to decreased predation pressure from the king snakes (Winne et al., 2007).

Enigmatic snake declines are not restricted to terrestrial species. Marine elapids (sea-snakes) have also experienced recent and dramatic declines (Elfes et al., 2013). For example, 14 species of marine elapids have been recorded at Ashmore Reef in the Timor Sea (Lukoschek et al., 2013). Surveys carried out in in 1973 and 1994 revealed a mean of 46 and 42 sea snakes per day respectively. These included the same nine species. However, in 2002, only five species were recorded during 10 days of intensive surveying and subsequent surveys also showed a steep drop in numbers observed. Four previous species recorded from Ashmore Reef (*Aipysurus apraefrontalis, Aipysurus foliosquama, Aipysurus duboisii* and *Hydrophis coggeri*) have not been seen since 1994 and two additional species (*Aipysurus peroni* and *Emydocephalus annulatus*) have not been sighted since 2005 (Lukoschek et al., 2013). Ashmore Reef is a strictly protected reef so actual causes of decline are uncertain but could be a combination of habitat degradation and climate change affecting the viability of populations

(Lukoschek et al., 2013). A bleaching effect of coral occurred in 2003, but declines preceded this date. These declines are not restricted to Ashmore Reef and sea snake declines elsewhere have been recorded. Elfes et al. (2013) assessed the conservation status of marine elapid snakes and found that 9% are threatened with extinction and a further 6% are near threatened. The loss of coral reefs and coastal habitat, as well as incidental bycatch are thought to be contributory factors towards declines.

1.4.4 Habitat destruction, fragmentation and environmental degradation

Loss of natural habitat through anthropogenic influence is one of the greatest threats to global biodiversity (WWW Living Planet Report, 2014). Human population growth and associated demands on natural resources have drastically altered natural environments, leading to the decline and extinction of many species (Ehrlich & Ehrlich, 1981, 2008). Snakes have both benefited and declined through human disturbance to ecosystems, depending on whether they have generalist or specialist habitat and dietary requirements, and their adaptability to a changing environment (Greene, 2000). Agriculture can also be detrimental to many species through loss of unique habitat, but some species can benefit due to an increase in prey availability such as rodents, and artificial structures such as walls and outbuildings. For example, rice paddies in Asia may create suitable habitat for cobras (*Naja*), which are catholic in their diet and shelter in burrows alongside raised earth turfs. Rodents attracted to these agricultural fields create an abundant food resource for cobras (Mattison, 1995). This increase in cobra biomass may also lead to an associated increase in snakebite risk to rural communities (Fry, 2018). However, arboreal pit-vipers that occurred in former forest, may in turn experience rapid declines because of forest clearing and lack of suitable prey, such as birds and arboreal lizards.

Agricultural land use is identified as having a profound influence on species richness, for example in the Iberian Peninsula (Ribeiro et al., 2009). The use of buffer strips by snakes in agricultural land was reviewed by Knoot and Best (2011). In south-eastern Iowa, USA, these buffer strips can be important corridors for snake dispersal (Knoot & Best, 2011). In the USA, anthropogenic changing land use including urbanization and agriculture has eliminated timber rattlesnakes (*Crotalus horridus*) from much of its former range (Rudolph & Burgdorf, 1997). Male timber rattlesnakes cover greater distances, particularly during the breeding season (late summer and fall) and many are killed on roads (of 21 individuals of known sex recorded on roads, 15 were adult males). It is predicted that dense road networks and associated traffic are responsible for the decline of timber rattlesnakes in eastern Texas, USA (Rudolph & Burgdorf, 1997). In a further study on *C. horridus*, Clark et al. (2011) highlighted a recent decline of the last remaining population in New Hampshire, USA, citing severe inbreeding depression because of isolation due to surrounding development and agriculture. Inbreeding depression also makes these snakes more susceptible to disease (Clark et al., 2011).

Anthropogenic changing land use including urban and agricultural development and associated transport networks is increasing exponentially and in turn isolating numerous snake populations that had former continuous distributions (Andrews & Gibbons, 2005). These isolated populations are showing increasing signs of genetic isolation and inbreeding depression, which is cause for conservation concern (Guicking et al., 2004; Clark et al., 2011; Sztencel-Jablonka et al., 2015). Northern pine snakes *Pituophis melanoleucus melanoleucus* in the New Jersey Pine Barrens, USA, face a variety of threats, most notably by increased human pressure on habitat for the development of residential and commercial properties, and increased associated road density and traffic is also leading to more of these snakes being killed on roads (Burger & Zappalorti, 2016).

A study by Beininger et al. (2012) on eastern indigo snakes (*Drymarchon couperi*) demonstrated that habitat fragmentation is likely to be the critical factor of this species persistence in its environment. Snakes in core conservation areas had a much higher survival rate compared with snakes in suburbs or along highways. *Drymarchon couperi* has declined over much of its former range and is now extirpated from Mississippi and Alabama, USA (Enge et al., 2013). Likewise, Godley and Moler (2013) showed substantial population declines of *D. couperi* in the Gulf Hammock Wildlife Management Areas in Florida, USA.

While anthropogenic habitat destruction and environmental degradation can be detrimental to many species, the creation of artificial refugia (such as building rubble) or the creation of wetlands can be beneficial to others, sometimes extremely so. Ackley and Meylan (2010) reported on a high biomass of water snakes (*Nerodia clarkii compressicauda*) in urban Florida, USA, which reached 25.4kg/ha (at a density of 159 snakes/ha) in artificial wetlands. Following herbicide use and subsequent vegetation loss, a noticeable decline was recorded and attributed to emigration due to loss of suitable habitat and not thought to be directly related to direct poisoning (Ackley & Meylan, 2010).

1.4.5 Road mortalities

Road mortality is relatively well documented in the literature and the emerging discipline of road ecology is becoming mainstream in ecological and conservation sciences (Kioko et al., 2015). Roads and its associated traffic have been implicated in the decline of numerous animal species, including snakes. For example, road mortality accounts for between 14 - 21% of the population p.a. for the copper-bellied water snake *Nerodia erythrogaster neglecta* in Indiana, USA, which experience high mortality as they cross over roads between wetland systems (Roe et al., 2006). A study conducted in Canada by Row et al. (2007) estimated up to nine adult black rat snakes *Pantherophis obsoleta* are killed annually by cars at a study site in Ontario

and that sustained mortality can have a pronounced negative effect on populations of long-lived species. Combined direct mortality and road avoidance can cause populations to become genetically isolated (Andrews et al., 2008). A study on the genetic structure in timber rattlesnakes in four different regions of New York, USA, showed significant effect on their genetic structure, gene flow and connectivity (Clark et al., 2010). Andrews and Gibbons (2005) found that smaller species avoided roads more than larger species. However, this may be biased towards temperate species or detection probability, as studies in South Africa show no distinction between smaller species and larger species (Schmidt and Downs in prep.) Protected areas such as national parks or nature reserves, or roads traversing near protected areas, are not immune from roadkill (Collinson et al., 2015). A study in the Iberian Peninsula by Garriga et al. (2012) showed that reptile and amphibian road mortality was higher in protected areas that outside these regions.

1.4.6 Fire

Fire is an important component ensuring the health and functioning of many ecosystems (Whelan, 1995; Bond & Keeley, 2005). However, fire suppression through anthropogenic management practices or too frequent fires can drastically alter the ecosystem to the detriment of the organisms adapted to that environment. Alien invasive plants can also have a detrimental impact on fire regimes with 'hotter' burns leading to a scorched earth scenario (Bond & Van Wilgen, 1996). Unseasonal fires can kill numerous ectothermic animals (and small mammals) out foraging and not having enough time to seek suitable shelter.

Annual burning of grasslands in Swaziland has been shown to be detrimental to the survival of the herpetofauna especially grass lizards (*Chamaesaura spp.*) (Boycott, 2015) and frequent fires may lead to the extinction of local populations (Bates et al., 2014). However, Brown et al. (2014) found in Bastrop Country, Texas, that a high severity wild fire which

burned 39% of the area had very little impact on the herpetofauna. However, substrate type, reptile behaviour and seasonal activity must be taken into consideration, as impact may vary considerably between species and at different seasons (Steen et al., 2015). In comparison, Steen et al. (2015) investigated prescribed burns to improve habitat quality for the endangered eastern massassauga rattlesnake (*Sistrurus catenatus catenatus*) but cautioned against making any inferences due to limited statistical analyses. A comparative study in San Mateo County, California with western yellow-bellied racers (*Coluber constrictor mormon*) found no differences in survival or body condition pre-and post-fire events (Thompson et al., 2013).

Apart from direct impact on wildlife, fires can change the vegetational composition over time and in turn species presence. For example, Ruthven's gopher snake (*Pituophis ruthveni*) has a strong association with pocket gophers (*Geomys breviceps*). Alteration of original pine long-leaf pine due to altered fire regimes and replacement by other pine species has had a detrimental impact on predator-prey relationships. The altered herbaceous understorey provided necessary nutrition and shelter for the pocket gophers, but when destroyed, the gopher population crashed followed by the snakes, which also utilise their burrows for shelter (Rudolph & Burgdorf, 1997).

1.4.7 Ecological succession

As mentioned, the structural composition of an ecosystem and associated changes over time can have a detrimental or beneficial influence on snake populations. Overgrown forest was identified as a possible cause for the local extinction of asp vipers (*Vipera aspis*) in the Swiss Jura Mountains (Jaggi and Baur, 1999). Forest cover can be detrimental to species reliant on basking positions, particularly in temperate climates where ectotherms must make the most of a short season of activity (Lind et al., 2005). Bonnet et al. (2016), in western France, manipulated forest habitat by removing trees and allowing regrowth of scrubby vegetation,

discovered that these open shrubby areas were quickly colonised by asp vipers and the population increased.

The removal of large herbivorous animals from the environment can also alter the vegetational composition and in turn promote or deter species from occupying that habitat. For example, a study conducted in Kenya showed that olive sand snake (*Psammophis mossambicus*) populations were significantly higher in experimental plots where large herbivores were absent and rodent populations were higher (McCauley et al., 2006).

1.4.8 Climate change

Relatively few studies on the impact of global climate change on snake populations have been conducted. However, there are numerous studies on other ectothermic vertebrates, such as lizards, indicating that climate change may have a detrimental impact on snake diversity and distributions, if not directly on thermal requirements, then on spatial changes in habitats and environment (Rohr & Palmer, 2013). Indirectly, climate change may impact on food resources, such as amphibians, which could lead to population declines in aquatic snake species which consume frogs as a food resource (Pomara et al., 2014).

Long-term studies document temporal variation attributable to natural causes, e.g. Shine (1991) documented a decline in Australian red-bellied black snakes (*Pseudechis porphyriacus*) during drought due to lack of amphibian prey. Natural fluctuations and local extinctions are common place in ecology. However, predicted climate change effects, and various modelling scenarios could either jeopardize or increase the spatial distribution of various species (Lopez-Calderon, 2016). Studies in the Iberian Peninsula predict that arid adapted species may move further north into Europe in the event of warmer climatic conditions (Aruajo et al., 2006).

Climate induced reductions in tree growth may be associated with reduction in accumulated forest floor leaf litter, which in turn alters population structure within terrestrial herpetofauna reliant on leaf litter. For example, in Costa Rica, a study showed that a 50% reduction in leaf litter had a profound effect on the number of amphibians and reptiles collected (Whitfield et al., 2014).

Reptiles and amphibians are generally considered to be poor dispersers. Climate change in Europe, using different climate modelling projections to determine whether the range amphibians and reptiles will expand or contract, has shown that increasing temperatures can lead to lower rainfall which in turn will affect amphibian breeding and population stability (Collins & Storfer, 2003). Changes to climate have also been shown to alter vegetation and in turn trophic levels which could disrupt prey availability (Parmesan, 2006). Within southern Europe, unfilled niches for snakes could expand their ranges in a warmer climate (Araújo et al., 2006).

While climate change is generally predicted to lead to warmer mean annual temperatures and increasing aridity, extreme weather events such as flooding are predicted in alternate scenarios. Flooding events have been documented as a cause in the decline of several snake species, including pygmy rattlesnakes (*Sistrurus spp.*) and Australian water pythons (*Liasis fuscus*) (Ujvari et al., 2016). A dataset analysed from 1991-2014 on predator-prey demography of Australian water pythons and dusky rats (*Rattus colletti*) in the Northern Territory of Australia found that two major flooding events in 2007 and 2011 extirpated the dusky rats, which followed by a crash in the water python population (Ujvari et al., 2016). This study may present a perfectly natural climatic cycle and not related in any way to anthropogenic induced climate change. However, predicted climate change modelling must be incorporated into population studies in order to infer likely expansion or contraction of a species range, including its thermic thresholds.

Predator-prey relationships and associated declines have been reported in other species (Lind et al., 2005). With widespread reports of amphibian population declines with climate change (Lips, 1999; Vitt et al., 1990), snakes which feed on amphibians may also be at risk. Matthews et al. (2002), researching the relationship between mountain garter snakes (*Thamnophis elegans elegans*) and their amphibian prey in the Sierra Nevada, USA, found that the probability of finding snakes in lakes with amphibians was 30 times greater than in those aquatic systems without amphibians. If the predators primary prey base declines, it stands to reason that the predator will experience a similar decline.

Climate change could have a potential impact on reptiles where temperature sex-determination is a factor in reproduction, particularly for crocodiles, chelonians and some lizards (Janzen, 1994). The impact on snake reproduction is not fully understood.

1.4.9 Chemical pollutants and toxins

Agricultural and industrial chemicals, including petrochemicals, herbicides and pesticides are of important environmental concern (Hopkins et al., 2001). Raptors feeding on animals with high levels of heavy metals and organophosphates are known to lay eggs with reduced calcareous shells and other deformations. The effect of contaminants on reptiles is not fully understood, but several studies have shown that they can have a detrimental effect, especially on those species strongly associated with wetlands. In crocodiles, many of these chemicals act as endocrine disruptors affecting reproduction and population stability (Guilette & Crain, 1996). For example, coal polluted wetlands can affect the metabolic processes in banded water snakes *Nerodia fasciata* (Hopkins et al., 1999). Heavy metals and organophosphates may also influence swimming behaviour, growth and reproduction in snakes exposed to such elements. Pesticides in aquatic environments also disrupt the endocrine system of animals (Hopkins et

al., 2005; Khan and Law, 2005). High levels of mercury have been reported in cottonmouths (*Agkistrodon piscivorus*) from north-eastern Texas (Rainwater et al., 2005).

1.4.10 Disease and pathogens

Snakes are susceptible to many diseases, pathogens and parasites. Parasites include external mites and ticks (Acari) and a range of internal parasites, including nematodes and various blood parasites. Parasitic overload may weaken and kill infected snakes, but these are usually on snakes already overburdened by environmental stress, suppressed immunity or physical injury. Wild snakes placed in captivity are susceptible to high parasitic loads, either through increased stress or inadequate temperature and hygiene. Under normal environmental conditions, parasites are unlikely to lead to detrimental population declines (Mullin & Seigel, 2009). However, habitat fragmentation has been shown to lead to interrupted gene flow, effectively weakening the genetic integrity of populations and making individuals more susceptible to disease and parasites (Lorch, 2016).

Of concern, however, is the recently documented snake fungal disease (SFD) (*Ophidiomyces ophidiicola*) (Allender et al., 2015; Bohuski et al., 2015). SFD is an alarming emerging fungal disease implicated in the recent decline of several North American snake species (McBride, 2015; Tetzlaff, 2015). From around 2006, SFD has been recorded in several populations of wild snakes in North America and now known to have infected no less than 30 species (Lorch et al., 2016). It has also been recorded in captive snakes in the United Kingdom, Germany and Australia, and may be more widespread in wild snakes outside of North America. (Allender et al., 2015; Bohuski et al., 2015; McBride et al., 2015; Tetzlaff et al., 2015; Last et al., 2016; Lorch et al., 2016; Ravesi et al., 2016). The epidemiology of *O. ophidiicola* is currently the subject of numerous ongoing studies. Timber rattlesnakes (*C. horridus*) and pygmy rattlesnakes (*Sistrurus catenatus*), which have been declining throughout their range

due to numerous factors, are also highly susceptible to SFD, which cause skin lesions and infections and impacts on the overall health of the snake (Allender et al., 2015). It is suspected that inbreeding depression and environmental stressors may be contributing factor to the very recent emergence of this fungal disease.

1.4.11 Invasive alien species

The IUCN has listed alien invasive species as one of the major drivers of ecological change and a serious threat to biodiversity across the globe (Bellard et al., 2016). The introduction of invasive species can have a profound effect on native fauna and flora, especially on islands. Introduced mongoose (*Herpestes javanicus*) are implicated in the decline of several endangered Caribbean snakes (Mattison, 1995). Bellard et al. (2016) identified 1 372 vertebrates threatened by the introduction of alien invasive species, of which 161 were reptiles. Introduced cane toads (*Rhinella marina*) in Australia have had a detrimental impact on snakes which feed primarily on amphibian prey (Shine, 2003). Approximately 30% of Australia's terrestrial snake species are at risk from the toxins while ingesting cane toads (Phillips et al., 2003). Feral and domestic cats are also known to have a devastating impact on reptiles. A study by Woinarski et at. (2018) showed that an estimated 1.3 million reptiles are killed daily by cats in Australia.

Less understood is the impact invasive plants have on influencing snake populations, but equal to ecological succession, invasive plants can alter the composition of the vegetation matrix and this can impact predator-prey relationships, or alter micro-climates thereby influencing ectothermic behavioural patterns.

1.4.12 Trade and exploitation

The global trade in snakes and snake products is extensive (Zhou & Jiang, 2004; Brooks et al., 2010). Snakes are heavily exploited as food for human consumption in many parts of the world

(Mattison, 1995; Greene, 1997; Shine, 2003). Skin, fat and internal organs are used in a diverse range of traditional medicines and even cosmetics. Snake skin is highly sought after for the fashion industry in the manufacture of handbags, belts, shoes and other ornaments (Murray-Dickson et al., 2017). The demand for snakes as exotic pets as increased exponentially with a continuous demand for rare and beautifully ornamented species. Adders and vipers, many with very limited ranges, such as African tree vipers (*Atheris sp.*), dwarf adders (*Bitis sp.*) and Asian and Neotropical tree vipers (*Trimeresurus sp.* and *Bothriechis sp.*), are much sought after, placing immense pressure on their relatively small populations (Maritz et al., 2016). Wagner's viper (*Vipera wagneri*) populations have been reduced due to collecting for the pet trade (Nilson et al., 1990).

Pythons and boas are also heavily exploited for the pet trade, but updated data are needed to understand current impact, as many species are now successfully bred and reared in captivity (Murray-Dickson et al., 2017). Captive animals are generally preferred by hobbyists because of less risk of disease and better adaptability to captivity. Added to this, unusual colour variants and mutations are highly prized over natural colours, therefore promoting selective captive breeding. Over-exploitation for skins and habitat destruction remains a serious threat to boas and pythons (Murray-Dickson et al., 2017).

Reptiles are also heavily utilised as a form of protein in tropical and sub-tropical regions (Segniogbeto, 2013). Utilisation for food is well-documented in chelonians (freshwater and marine turtles) and crocodiles. Snakes are particularly used in south-east Asia and China as a food source (Shine et al., 1995) or as feed for other animals (Brooks et al., 2010). With fluctuating prices in crocodile skins, crocodile farms in Cambodia have turned to snakes as a cheaper dietary supplement for crocodile feed (Brooks et al., 2010). For example, an estimated 2.7 to 12.2 million snakes are sold to crocodile farms in Cambodia annually (Brooks et al., 2010).

Du (2001) estimated that almost one million *Deinagkistrodon acutus* were harvested annually in the Shanghai region of China in the early 1990s. Live snakes and skins exported from China between 1990-2001 were estimated at approximately 8.9 million of at least 15 species (Du. 2001). Snakes imported into China during the same period were around 9 million (Zhou and Jiang, 2004). Captive breeding in China is not a commercially viable option, therefore wild snakes are in high demand (Zhou and Jiang, 2004). The Chinese snake crisis is comparable to the Asian turtle crisis (Sharma, 1999). An investigation into breeding farms in Indonesia demonstrated that at least 80% of exported green tree pythons (*Morelia viridis*) are illegally collected from wild populations. (Lyons & Natusch, 2011).

Many snake species are also used in traditional medicine, especially in Africa and Asia. Segniagbeto et al. (2013) surveyed markets in Lomé, Togo and found that at least 37 different species of reptiles are utilised, 17 of them snakes. The direct impact on snake populations for traditional medicine use is hard to gauge comparative to habitat loss and degradation, agriculture and urban development, but may be detrimental to rare or endangered species. In Togo, at least, most of the species recorded are wide-ranging and common, although some, such as the ball python *Python regius*, are believed to be experiencing declines due to over collecting (Spawls et al., 2018).

1.5 DISCUSSION

Based on the ever-increasing pool of scientific publications on snake conservation and ecology, there is no doubt that snake populations, of at least a substantial percentage of species, are indeed experiencing alarming population declines. These declines are analogous to general biodiversity declines experienced in other taxonomic groups. The Global Living Planet Index shows a 52% decline in vertebrate populations between 1970-2010 (WWF Living Planet Report, 2014).

It is also clear that snakes are facing a multitude of threats ranging from habitat destruction and road mortality through to climate change, disease and inbreeding depression. Most observable declines are a result of a combination of factors, often interrelated and overall leading to a species demise. However, the challenge is deciphering immediate anthropogenic induced declines over long-tern natural population fluctuations and addressing appropriate conservation measures to prevent further declines. "The means of determining a species 'conservation status is a rigorous and time-intensive process, and therefore counts of officially recognized endangered and threatened species are likely to grossly underestimate the number of imperilled species" (Gibbons et al., 2000).

Well thought and robust survey methods are critical in assessing the occurrence of species in each landscape. This is especially important when trying to assess population variance in secretive and cryptic ectotherms like snakes. Much has been written about survey methodology and effort (see Ryan et al., 2002; Santos et al., 2007; Steen, 2010; Sewell et al., 2012; Loos et al., 2015).

Current conservation assessments make extensive use of plotted distribution localities to infer a species' distribution and status. Natural history collections can be pivotal repositories of information is assessing species declines (see Shaffer et al., 1988).

This review has shown a strong bias towards snake population studies in North America, and to a lesser extent Europe, with relatively little attention given to the tropics or sub-tropical regions of the world. This disparity was also highlighted by Gardner et al. (2007) who found that nearly half of herpetofaunal studies relating to habitat change were from North America.

Whilst long term population studies on snakes would be ideal, the reality is that we are presently reliant largely on anecdotal reports, barring a few long-term monitoring projects in North America, Europe and Australia. Concerted effort is needed in the tropics and sub-tropics

where snakes are heavily utilised and habitat destruction through deforestation and subsistence agriculture is intense. The alarming figures given in Asia and China for snake utilisation is bound to push many species to the brink of extinction.

Whilst baseline data and conservation assessments are critically important in understanding population structure and variance, conservation needs and priorities, such data cannot be used in isolation without direct integration into anthropogenic socio-politic studies. Human population growth, socio-political trends, economic stability, conflict, urban and agricultural expansion must be integrated into conservation assessments. Without integration and the ability to assess future anthropogenic trends and associated ecological disturbance, all conservation efforts will be in vain and short term.

1.6 AIM OF THE THESIS

As highlighted reptile declines have been documented from across the globe in recent decades. This is a result of anthropogenic transformation of the landscape, including habitat destruction, environmental degradation, road mortality, leaching of chemicals and pollutants into the environment, genetic isolation and disease. More recently, several well-studied declines affecting snakes have been documented in the literature. Most studies emanate from North America and Europe, with a small percentage from Australia. Due to the absence of long-term site monitoring in Africa, the extent of snake population declines is mostly unknown and at best, speculative. This thesis aimed to provide baseline data from South Africa based on long-term field observations and accumulative data spanning a period of approximately 30 years, from 1988 – 2018.

1.7 STRUCTURE OF THE THESIS

The main body of this thesis is organised as manuscripts prepared for publication in peer-reviewed journal articles. The first chapter (Chapter 1) is the Introduction which provides the literature review of the background and concepts covered in this study. The next four chapters (Chapter 2, 3, 4, 5 and 6) are mainly data chapters with each one covering a specific objective. Each chapter is formatted for submission to an international peer review journal so some repition was unavoidable.

In Chapter 1, the published literature globally pertaining to snake conservation, population ecology and documented snake population declines, and the contributing factors thereof were reviewed. In Chapter 2, the current understanding of global snake diversity, conservation and systematics to quantify species diversity and conservation trends in extant snake species was reviewed. In Chapter 3, snake data pertaining to road mortality based on a case study undertaken along the R516 national road in Limpopo Province, South Africa are presented. In Chapters 4 and 5, long-term snake data from two different, well-defined, field study sites – one site situated in a former grassland habitat in Gauteng Province, which is now completely transformed, and a second site on the lower South Coast of KwaZulu-Natal, which has experienced much lower rates of habitat transformation, are presented. In Chapter 6, a common, widely distributed snake species, the rinkhals (*Hemachatus haemachatus*), was selected as a species-specific candidate to show the effects of urbanisation. A final concluding chapter follows.

1.6 REFERENCES

Adams, C.E., Thomas, J.K., Strnadel, J.K. & Jester, L. 1994. Texas rattlesnake roundups: implications of unregulated commercial use of wildlife. *Wildlife Society Bulletin* 22: 234-330.

Ackley, J.W. & Meylan, P.A. 2010. Watersnake eden: use of stormwater retention ponds by mangrove saltmarsh snakes (*Nerodia clarkia compressicauda*) in urban Florida. *Herpetological Conservation and Biology* 5 (1): 17-22.

Alford, R. A. & Richards, S. J. 1999. Global amphibian declines: a problem in applied ecology. *Annual Review of Ecology and Systematics* 30: 133-165.

Allender, M.C., Dreslik, M., Wylie, S., Phillips, C., Wylie, D.B., Maddox, C., Delaney, M.A.& Kinsel, M.J. 2011. *Chrysosporium sp.* Infection in eastern massasauga rattlesnakes. *Emerging Infectious Diseases* 17: 2383-2384.

Allender, M.C., Raudabaugh, D.B., Gleason, F.H. & Miller, A.N. 2015. The natural history, ecology, and epidemiology of *Ophidiomyces ophiodiicola* and its potential impact on free-ranging snake populations. *Fungal Ecology*. doi:10.1016/j.funeco.2015.05.003

Andrews, K.M. & Gibbons, J.W. 2005. How do highways influence snake movement? Behavioural responses to roads and vehicles. *Copeia* 2005: 772-782.

Andrews, K.M. Gibbons, J.W. & Jochimsen, D.M. 2008. Ecological effects of roads on amphibians and reptiles: a literature review. *Herpetological Conservation* 3: 121-143.

Araújo, M.B., Thuiller, W. & R.G. Pearson. 2006. Climate warming and the decline of amphibians and reptiles in Europe. *Journal of Biogeography* 33: 1712-1728. doi:10.1111/j.1365-2699.2006.01482.x

Baier, F. & Wiedl, H-J. 2010. The re-evaluated conservation status of the mountain populations of the highly endangered Cyprus grass snake, *Natrix natrix cypriaca* (Hecht, 1930), with miscellaneous natural history notes. *Salamandra* 46 (1): 16-23.

Baker, S.J., Dreslik, M.J., Wylie, D.B. & Phillips, C.A. 2016. Sources of mortality in the endangered eastern massasauga (*Sistrurus catenatus*) in Illinois. *Herpetological Conservation and Biology* 11 (2): 335-343.

Bateman, H.L., Chung-MacCoubrey, A., Snell, H.L. & Finch, D.M. 2009. Abundance and species richness of snakes along the Middle Rio Grande riparian forest in New Mexico. *Herpetological Conservation and Biology* 4 (1): 1-8.

Bates, M.F., Branch, W.R., Bauer, A.M., Burger, M., Marais, J., Alexander, G.J. & De Villiers, M.S. (eds). 2014. Atlas and red list of the reptiles of South Africa, Lesotho & Swaziland. *Suricata* 1. South African National Biodiversity Institute, Pretoria.

Bauder, J.M. 2015. Factors influencing the display of multiple defensive behaviours in eastern indigo snakes (*Drymarchon couperi*). *Herpetological Conservation and Biology* 10 (2): 559-571.

Beane, J.C., Graham, S.P., Thorp, T.J. & Pusser, L.T. 2014. Natural history of the southern hognose snake (*Heterodon simus*) in North Carolina, USA. *Copeia* 2014 (1): 168-175. DOI: 10.1643/CH-13-044

Beebee, T. J. C. 1992. Amphibian decline? *Nature* 355:120.

Beebee, T.J.C., Wilkinson, J.W. & Buckley, J. 2009. Amphibian declines are not uniquely high amongst the vertebrates: trend determination and the British perspective. *Diversity* 1: 67-88. doi:10.3390/d1010067

Behrooz, R., Kaboli, M., Nourani, E., Ahmadi, M., Shabani, A.A., Yousefi, M., Asadi, A. & Rajabizadeh, M. 2015. Habitat modelling and conservation of the endemic Latifi's viper (*Montivipera latifii*) in Lar National Park, Northern Iran. *Herpetological Conservation and Biology* 10 (2): 572-582.

Bellard, C., Genovesi, P. & Jeshke, J.M. 2016. Global patterns in threats to vertebrates by biological invasions. *Proceedings of the Royal Society* B. 283: 20152454. doi:10.1098/rspb.2015.2454.

Böhm, M. et al. 2013. The conservation status of the world's reptiles. *Biological Conservation* 157: 372-385.

Bohuski, E., Lorch, J.M., Griffin, K.M. & Blehert, D.S. 2015. TaqMan real-time polymerase chain reaction for detection of *Ophidiomyces ophiodiicola*, the fungus associated with snake fungal disease. *BMC Veterinary Research* 11: 95. doi:10.1186/s12917-015-0407-8

Bond, W. J. & Van Wilgen, B. W. 1996. Fire and plants. Chapman and Hall, London, UK.

Bond, W. J. & Keeley, J. E. 2005. Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. *Trends in Ecology and Evolution* 20: 387-394.

Bonnet, X. Naulleau, G. & Shine, R. 1999. The dangers of leaving home: dispersal and mortality in snakes. *Biological Conservation* 89: 39-50.

Bonnet, X., Lecq, S., Lassay, J.L., Ballouard, J.M., Barbraud, C., Souchet, J., Mullin, S.J. & Provost, G. 2016. Forest management bolsters native snake populations in urban parks. *Biological Conservation* 193: 1-8. doi:10.1016/j.biocon.2015.11.001

Botts, E.A., Erasmus, B.F.N. & Alexander, G.J. 2015. Observed range dynamics of South African amphibians under conditions of global change. *Austral Ecology* 40: 309-317. doi:10.1111/aec.12215

Bouchot, R. (ed). 1994. Snakes – a natural history. Sterling Publishing, New York.

Boycott, R.C. 2015. Observations on the African grass lizards *Chamaesaura* FitZinger (Reptilia: Sauria: Cordylidae) in Swaziland, with emphasis on fire impacts on populations in Malolotja Nature Reserve. *Durban Natural Science Museum Novitates* 37: 30-39.

Breininger, D.R., Mazerolle, M.J., Bolt, M.R., Legare, M.L., Drese, J.H. & Hines, J.E. 2012. Habitat fragmentation effects on annual survival of the federally protected eastern indigo snake. *Animal Conservation* 15: 361-368. doi:10.1111.j.1469-1795.2012.00524.x

Broadley, D.G. 2002. A review of the species of *Psammophis* Boie found south of latitude 12°S (Serpentes: Psammophiinae). *African Journal of Herpetology* 51(2): 83-119.

Broadley, D.G. & Wüster, W. 2004. A review of the southern African 'non-spitting'cobras (Serpentes: Elapidae: *Naja*). *African Journal of Herpetology* 53(2): 101-122.

Brooks, S.E., Allison, E.H., Gill, J.A. & Reynolds, J.D. 2010. Snake prices and crocodile appetites: aquatic wildlife supply and demand on Tonle Sap Lake, Cambodia. *Biological Conservation*. 143: 2127-2135. doi:10.1016/j.biocon.2010.05.023

Brown, D.J., Duarte, A., Mali, I., Jones, M.C. & Forstner, M.R.J. 2014. Potential impacts of a high severity wildfire on abundance, movement, and diversity of herpetofauna in the Lost Pines Ecoregion of Texas. *Herpetological Conservation and Biology* 9 (1): 192-205.

Burbrink, F.T. 2001. Systematics of the Eastern Rat Snake complex (*Elaphe obsoleta*). *Herpetological Monographs* 15: 1-53.

Burger, J. & Zappalorti, R.T. 2016. Conservation and protection of threatened pine snakes (*Pituophis melanoleucas*) in the New Jersey Pine Barrens, USA. *Herpetological Conservation and Biology* 11 (2): 304-314.

Case, T.J. & Bolger, D.T. 1991. The role of introduced species in shaping the distribution and abundance of island reptiles. *Evolutionary Ecology* 5: 272-290.

Chinnadurai, S.K., Brown, D.L., Wettere, A.V., Tuttle, A.D., Fatzinger, M.H., Linder, K.E. & Harms, C.A. 2008. Mortalities associated with sepsis, parasitism, and disseminated round cell neoplasma in yellow-lipped sea kraits (*Laticauda colubrina*). *Journal of Zoo and Wildlife Medicine* 39: 626-630.

Chittaragi, J.B. & Hosetti, B.B. 2014. Road kill mortality of snakes (Squamata: Serpentes) in different land cover areas of Semi-Malnad region, Mid Western Ghats, Shimogo, India. *Current Biotica* 8 (1): 57-65.

Clark, R.W., Brown, W.S., Stetchert, R. & Zamudio, K.R. 2010. Roads, interrupted dispersal, and genetic diversity in timber rattlesnakes. *Conservation Biology* 24 (4): 1059-1069. doi:10.1111/j.1523-1739.2009.01439.x

Clark, R.W., Marchand, M.N., Clifford, B.J., Stetchert, R. & Stephens, S. 2011. Decline of an isolated timber rattlesnake (*Crotalus horridus*) population: interactions between climate change, disease, and loss of genetic diversity. *Biological Conservation* 144: 886-891. doi:10.1016/j.biocon.2010.12.001

Cogger, H. & Zweifel, R. (eds). 1992. Reptiles & Amphibians – a comprehensive illustrated guide by international experts. Smithmark Publishers, New York.

Collins, J. P. & Storfer, A. 2003. Global amphibian decline: sorting the hypotheses. *Diversity and Distributions* 9: 89-98.

Collinson, W.J., Parker, D.M., Bernard, R.T., Reilly, B.K., & Davies-Mostert, H.T. (2015). An inventory of vertebrate roadkill in the greater Mapungubwe Transfrontier conservation area, South Africa. *African Journal of Wildlife Research*, *45* (3): 301-311.

Covaciu-Marcov, S-D., Ferenti, S., Ghira, I.V. & Sas, I. 2012. High road mortality of *Dolichophis caspius* in southern Romania. Is this a problem? What can we do? *North-Western Journal of Zoology* 8 (2): 370-373.

Craig Rudolph, D. & Burgdorf, S.J. 1997. Timber rattlesnakes and Louisiana pine snakes of the West Gulf Coastal Plain: hypotheses of decline. *Texas Journal of Science* 49 (3): 111-122.

Craigie, I. D., Baillie, J. E. M., Carbone, C., Collen, B., & Hutton, J. M. 2010. Large mammal population declines in Africa's protected areas. *Biological Conservation* 143: 2221-2228.

DeGregorio, B.A., Nordberg, E.J., Stepanoff, K.E. & Hill. J.E. 2010. Patterns of snake road mortality on an isolated barrier island. *Herpetological Conservation and Biology* 5 (3): 441-448.

DeGregorio, B.A., Hancock, T.E., Kurz, D.J. & Yue, S. 2011. How quickly are road-killed snakes scavenged? Implications for underestimates of road mortality. *Journal of the North Carolina Academy of Science* 127 (2): 184-188.

Dodd, C.K., Enge, K.M. & Stewart, J.N. 1989. Reptiles on highways in north-central Alabama, USA. *Journal of Herpetology*. 23: 197-200.

El-Gabbas, A., El Din, S.B., Zalat, S. & Gilbert, F. 2016. Conserving Egypt's reptiles under climate change. *Journal of Arid Environments* 127: 211-221. doi:10.1016/j.jaridenv.2015.12.007

Elfes, C.T., Livingstone, S.R., Lane, A., Lukosche, V., Sanders, K.L., Courtney, A.J., Gatus, J.L., Guinea, M., Lobo, A.S., Milton, D., Rasmussen, A.R., Read, M., White, M-D., Sanciango, J., Alcala, A., Heatwole, H., Karns, D.R., Seminoff, J.A., Voris, H.K., Carpenter, K.E. & Murphy, J.C. 2013. Fascinating and forgotten: the conservation status of marine elapid snakes. *Herpetological Conservation and Biology* 8 (1): 37-52.

Enge, K.M., Stevenson, D.J., Elliott, M.J. & Bauder, J.M. 2013. The historical and current distribution of the eastern indigo snake (*Drymarchon couperi*). *Herpetological Conservation and Biology* 8 (2): 288-307.

Ehrlich, P. R. & Ehrlich, A. H. 1981. Extinction: the causes and consequences of the disappearance of species. Random House, New York.

Ehrlich, P. R. & Ehrlich, A. H. 2008. The Dominant Animal: human evolution and the environment. Island Press, Washington DC.

Fenker, J. Tedeschi, L.G., Pyron, R.A. & Nogueira, C. de C. 2014. Phylogenetic diversity, habitat loss and conservation in South American pitvipers (Crotalinae: *Bothrops* and *Bothrocophias*). *Diversity and Distributions* 20: 1108-1119. doi:10.1111/ddi.12217

Figueroa, A., McKelvy, A.D., Grismer, L.L., Bell, C.D. & Lailvaux, S.P. 2016. A species-level phylogeny of extant snakes with description of a new colubrid subfamily and genus. *PLoS One* 11 (19): e0161070. doi:10.1371/journal.pone.0161070

Fitzgerald, M., Shine, R. & Lemckert, F. 2004. Life history attributes of the threatened Australian snake (Stephen's banded snake *Hoplocephalus stephensii*, Elapidae). *Biological Conservation* 119: 121-128.

FitzSimons, F.W. 1919. The Snakes of South Africa. T. Maskew Miller, Cape Town.

Flecks, M., Weinsheimer, F., Böhme, W., Chenga, J., Lötters, S. & Rödder, D. 2012. Watching extinction happen: the dramatic decline of the critically endangered Tanzanian turquoise dwarf gecko, *Lygodactylus williamsi*. *Salamandra* 48 (1): 12-20.

Fontenot, L.W., Noblet, G.P. & Platt, S.G. 1994. Rotenone hazards to amphibians and reptiles. *Herpetological Review* 25: 150-153.

Foufopoulos, J. & Ives, A.R. 1999. Reptile extinctions on land-bridge islands: life-history attributes and vulnerability to extinction. *American Naturalist* 153: 1-25.

Fry, G.C., Milton, D.A. & Wassenberg, J.J. 2001. The reproductive biology and diet of sea snake bycatch of prawn trawling in northern Australia: characteristics important for assessing the impacts of populations. *Pacific Conservation Biology* 7: 55-73.

Fry, G. 2018. Snakebite: when the human touch becomes a bad touch. *Toxins* 10: 170. doi:10.3390/toxins100440170

Gardner, T., Barlow, J. & Peres, C. 2007. Paradox, presumption and pitfalls in conservation biology: the importance of habitat change for amphibians and reptiles. *Biological Conservation* 138: 166-179.

Garriga, N., Santos, X., Montori, A., Richter-Boix, A., Franch, M. & Llorente, G.A. 2012. Are protected areas truly protected? The impact of road traffic on vertebrate fauna. *Biodiversity Conservation* 21: 2761-2774. doi:10.1007/s10521-012-0332-0

Gascon, C., Brooks, T.M., Contreras-MacBeath, T., Heard, N., Konstant, W., Lamoreux, J., Launay, F., Maunder, M., Mittermeier, R.A., Molur, S., Khalifa Al Mabarak, R., Parr, M.J., Rhodin, A.G.J., Rylands, A.B., Soorae, P., Sanderson, J.G. & Vié, J-C. 2015. The importance and benefits of species. *Current Biology* 25: 431-438. DOI: 10.1016/j.cub.2015.03.041

Gibbons, J.W., Scott, D.E., Ryan, T.J., Buhlmann, T. D., Metts, B.S., Greene, J.L., Mills, T., Leiden, Y., Poppy, S. & C.T. Winne. The global decline in reptiles, Déjà Vu amphibians. *BioScience* 50 (8): 653-666.

Gibson, J.D. & Merkle, D.A. 2004. Road mortality of snakes in central Virginia. *Banisteria* 24: 8-14.

Godley, J.S. & Moler, P.E. 2013. Population declines of eastern indigo snakes (*Drymarchon couperi*) over three decades in the Gulf Hammock Wildlife Management Areas, Florida, USA. *Herpetological Conservation and Biology* 8 (2): 359-365.

Greene, H. 1997. Snakes – The Evolution of Mystery in Nature. University of California Press.

Guicking, D., Herzberg, A, & Wink, M. 2004. Population genetics of the dice snake (*Natrix tessellata*) in Germany: implications for conservation. *Salamandra* 40 (3/4): 217-234.

Guilette, L. J. Jr. & Crain, D. A. 1996. Endocrine-disrupting contaminants and reproductive abnormalities in reptiles. *Comments in Toxicology* 5: 381-399.

Guinea, M.L. & Whiting, S.D. 2005. Insights into the distribution and abundance of sea snakes at Ashmore Reef. *Beagle Supplement*. 1: 199-205.

Guinea, M.L. 2012. Dwindling sea snakes at Ashmore Reef: searching for an elephant in the room. *Integrative and comparative Biology* 52 (Suppl.1) E255.

Hall, L.E. 2014. Poster: Habitat suitability, occupancy and a novel monitoring technique for an imperilled reptile (*Nerodia erythrogaster neglecta*). Pardue University, Fort Wayne.

Halliday, T. & Adler, K. (eds). 2002. The new encyclopedia of reptiles and amphibians. Oxford University Press, Oxford.

Halstead, B.J., Skalos, S.M., Wylie, G.D. & Casazza, M.L. 2015. Terrestrial ecology of semi-aquatic giant garter snakes (*Thamnophis gigas*). *Herpetological Conservation and Biology* 10 (2): 633-644.

Hamer, A.J. 2010. The response of herpetofauna to urbanization: inferring patterns of persistence from wildlife databases. *Austral Ecology* 35: 568-580.

Hanson, K.M. & McElroy, E.J. 2015. Anthropogenic impacts and long-term changes in herpetofaunal diversity and community composition on a barrier island in the southwestern United States. *Herpetological Conservation and Biology* 10 (2): 765-780.

Hawlitschek, O., Nagy, Z.T. & Glaw, F. 2012. Island evolution and systematic revision of Comoran snakes: why and when subspecies still make sense. *PLoS One* 7(8): e42970 doi:10.1371/journal.pone.0042970.

Hayward, M.W. 2011. Using the IUCN Red List to determine effective conservation strategies. *Biodiversity Conservation* 20: 2563-2573 doi: 10.1007/s10531-011-0091-3

Hopkins, W.A., Rowe, C.L. & Congdon, J.D. 1999. Elevated trace element concentrations and standard metabolic rate in banded water snakes (*Nerodia fasciata*) exposed to coal combustion wastes. *Environmental Toxicology and Chemistry*. 18: 1258-1263.

Hopkins, W.A., Roe, J.H., Snodgrass, J.W., Jackson, B.P., Kling, D.E., Rowe, C.L. & Congdon, J.D. 2001. Nondestructive indices of trace element exposure in squamate reptiles. *Environmental Pollution* 115: 1-7.

Hopkins, W.A., Winne, C.T. & Durant, S.E. 2005. Differential swimming performance of two natricine snakes exposed to a chlorineesterase-inhibiting pesticide. *Environmental Pollution* 133: 531-540.

Hopkins, W.A & Winne, C.T. 2006. Influence of body size on swimming performance of four species of neonatal natricine snakes acutely exposed to a chlorineesterase-inhibiting pesticide. *Environmental Toxicology and Chemistry*. 25: 1208-1213.

Hubbard, K.A. & Chalfoun, A.D. 2012. An experimental evaluation of potential scavenger effects on snake road mortality detections. *Herpetological Conservation and Biology* 7 (2): 150-156.

Isemonger, R.M. 1955. Snakes and Snake Catching in southern Africa. Howard Timmins, Cape Town.

Isemonger, R.M. 1962. Snakes of Africa – southern, central and east. Nelson, Johannesburg.

Iskandar, D.T. & Erdelen, W.R. 2006. Conservation of amphibians and reptiles in Indonesia: issues and problems. *Amphibian and Reptile Conservation* 4 (1): 60-87.

Jackson, K. & Blackburn, D.C. 2010. A survey of amphibians and reptiles at degraded sites near Pointe-Noire, Kouilou Province, Republic of Congo. *Herpetological Conservation and Biology* 5 (3): 414-429.

Jacobsen, E.R. 1993. Implications of infectious diseases for captive propagation and introduction programs of threatened/endangered reptile. *Journal of Zoo and Wildlife Medicine* 24: 245-255.

Jaggi, C & Baur, B. 1999. Overgrowing forest as a possible cause for the local extinction of *Vipera aspis* in the northern Swiss Jura mountains. *Amphibia-Reptilia* 20: 25-34.

Janzen, F.J. 1994. Climate change and temperature dependent sex determination in reptiles. *Proceedings of the National Academy of Sciences of the United States of America* 91: 7487-7490.

Jelić, D., Ajtic, R., Sterijovski, B., Crnobrynja-Isailović, Lelo, S. & Tomović, L. 2013. Legal status and assessment of conservation threats to vipers (Reptilia: Squamata: Viperidae) of the Western and Central Balkans. *Herpetological Conservation and Biology* 8 (3): 764-770.

Jochimsen, D.M., Peterson, C.R. & Harmon, L.J. 2014. Influence of ecology and landscape on snake road mortality in a sagebrush-steppe ecosystem. *Animal Conservation* 17: 583-592. doi:10.1111.acv.12125.

Jones, T.R., Babb, R.D., Hensley, F.R., LiWanPo, C. & Sullivan, B.K. 2011. Sonoran Desert snake communities at two sites: concordance and effects on increased road traffic. *Herpetological Conservation and Biology* 6 (1): 61-71.

Kelly, C.M.R., Branch, W.R., Broadley, D.G., Barker, N.P. & Villet, M.H. 2011. Molecular systematics of the African snake family Lamprophiidae Fitzinger, 1843 (Serpentes: Elapoidea), with particular focus on the genera *Lamprophis* Fitzinger 1843 and *Mehelya*

Csiki 1903. *Molecular Phyogenetics and Evolution* 58: 415-426. doi:10.1016/j.ympev.2010.11.010

Khan, M.Z. & Law, F.C.P. 2005. Adverse effects of pesticides and related chemicals on enzyme and hormone systems of fish, amphibians and reptiles: a review. *Proceedings of the Pakistan Academy of Science* 42 (4): 315-323.

Kioko, J., Kiffner, C., Jenkins, N. & Collinson, W.J. 2015. Wildlife roadkill patterns on a major highway in northern Tanzania. *African Zoology* 50 (1): 17-22. doi:10.1080/15627020.2015.1021161

Knoot, T.G. & Best, L.B. 2011. A multiscale approach to understanding snake use of conservation buffer strips in an agricultural landscape. *Herpetological Conservation and Biology* 6 (2): 191-201.

Krysko, K.L. & Smith, D.J. 2005. The decline and extirpation of the kingsnake in Florida. In: Amphibians and Reptiles Status and Conservation in Florida. Kriger Publishing Company, Malabar, Florida.

Lips, K. R. 1999. Mass mortality and population declines of anurans at an upland site in western Panama. *Conservation Biology* 13: 117-125.

Loos, J., Hanspach, J., von Wehrden, H., Beldean, M., Moga, C.I. & Fischer, J. 2015. Developing robust field survey protocols in landscape ecology: a case study on birds, plants and butterflies. *Biodiversity Conservation* 24: 33-46.

Lorch, J.M. Knowles, S., Lankton, J.S., Michell, K., Edwards, J.L., Kapfer, J.M., Staffen, R.A., Wild, E.R., Schmidt, K.Z., Ballmann, A.E., Blodgett, D., Farrell, T.M., Glorioso, B.M., Last, L.A., Price, S.J., Schuler, K.L., Smith. C.E., Wellehan, J.F.X. Jr & Blehert, D.S. 2016. Snake fungal disease: and emerging threat to wild snakes. *Philosophical Transactions of the Royal Society* B 371: 20150457. doi:10.1098/rstb.2015.0457

Lovich, R.E., Grismer, L.L. & Danemann, G. 2009. Conservation status on the herpetofauna of Baja California, Mexico and associated islands in the Sea of Cortez and Pacific Ocean. *Herpetological Conservation and Biology* 4 (3): 358-378.

Lukoschek, V., Beger, M., Ceccarelli, D., Richards, Z. & Pratchett, M. 2013. Enigmatic declines of Australia's sea snakes from a biodiversity hotspot. *Biological Conservation* 166: 191-202. doi:10.1016/j.biocon.2013.07.004

Lyons, J.A. & Natusch, D.J.D. 2011. Wildlife laundering through breeding farms: illegal harvest, population declines and a means of regulating the trade of green pythons (*Morelia viridis*) from Indonesia. *Biological Conservation* 144: 3073-3081.

Madsen, T., Ujvari, B. & Olsson, M. 2005. Old pythons stay fit: effects of haematozoan infections on life history traits of a large tropical predator. *Oecologica* 142: 407-412.

Madsen, T. & Ujvari, B. 2011. The potential demise of a population of adders (*Vipera berus*) in Smygehuk, Sweden. *Herpetological Conservation and Biology* 6 (1): 72-74.

Menegon, M., Davenport, T.R.B. & Howell, K.M. 2011. Description of a new and critically endangered species of *Atheris* (Serpentes: Viperidae) from the Southern Highlands of Tanzania, with an overview of the country's tree viper fauna. *Zootaxa* 3120: 43-54.

Marchand, M.N. & Litvaitis, J.A. 2004. Effects of habitat features and landscape composition on the population structure of a common aquatic turtle in a region undergoing rapid development. *Conservation Biology* 18 (3): 758-767.

Maritz, B., Penner, J., Martins, C. Crnobrnja-Isailović, J., Spear, S., Alencar, L.R.V., Sigala-Rodriguez, J., Messenger, K., Clark, R.W., Soorae, P., Luiselli, L., Jenkins, C.& Greene, H.W. 2016. Identifying global priorities for the conservation of vipers. *Biological Conservation* 204: 94-102. doi:10.1016/j.biocon.2016.05.004

Martin, W.H. Life history constraints on the timber rattlesnake (*Crotalus horridus*) and its climatic limits. In: Biology of the Vipers, 285-306.

Martins, M., Sawaya, R.J. & Marques, O.A.V. 2008. A first estimate of the population size of the critically endangered lancehead, *Bothrops insularis*. *South American Journal of Herpetology* 3: 168-174.

Matthews, K.R., Knapp, R.A. & Pope, K. 2002. Garter snake distributions in high-elevation aquatic ecosystems: is there a link with declining amphibian populations and non-native trout introductions? *Journal of Herpetology* 36 (1): 16-22.

Mattison, C. 1995. The encyclopedia of snakes. Blandford, UK.

McBride, M.P., Wojick, K.B., Georoff, T.A., Kimbro, J., Garner, M.M., Wang, X., Childress, A.L. & Wellehan, J.F.X. 2015. *Ophidiomyces ophiodiicola* dermatitis in eight free-ranging timber rattlesnakes (*Crotalus horridus*) from Massachusetts. *Journal of Zoo and Wildlife Medicine*. 46 (1): 86-94.

McCauley, D.J., Keesing, F., Young, T.P., Allan, B.F. & Pringle, R.M. 2006. Indirect effects of large herbivores on snakes in an African savanna. *Ecology* 87 (10): 2657-2663.

McLeod, R.F. & Gates, J.E. 1998. Response of herpetofaunal communities to forest cutting and burning at Chesapeake Farms, Maryland. *American Midland Naturalist* 139: 164-177.

Means, D.B. 2009. Effects of rattlesnake roundups on the eastern diamondback rattlesnake (*Crotalus adamanteus*). *Herpetological Conservation and Biology* 4 (2): 132-141.

Mendelson, J.R. III & Jennings, W.B. 1992. Shifts in the relative abundance of snakes in desert grasslands. *Journal of Herpetology* 26: 38-45.

Menegon, M., Davenport, T.R.B. & Howell, K.M. 2011. Description of a new and critically endangered species of *Atheris* (Serpentes: Viperidae) from the Southern Highlands of Tanzania, with an overview of the country's tree viper fauna. *Zootaxa* 3120: 43-54.

Mullen, S. J. & Seigel, R. A. 2009. Snakes: ecology and conservation. Ithaca, New York. Cornell University Press.

Murray-Dickson, G., Ghazali, M., Ogden, R., Brown, R. & Auliya, M. 2016. Phylogeography of the reticulated python (*Malayopython reticulatus* ssp.): Conservation implications for the worlds' most traded snake species. *PLoS One* 12(8): e0182049. 17https://doi.org/10.1371/journal.pone.0182049

Osborne, W. S., Hunter, D. A. & Hollis, G. L. 1999. Population declines and range contraction in Australian alpine frogs. In: Campbell, A. (ed) *Declines and disappearances in Australian Frogs*, pp.145-157. Environment Australia, Canberra, Australia.

Parker, W.S. & Brown, W.S. 1973. Species composition and population changes in two complexes of snake hibernacula in northern Utah. *Herpetologica* 29: 319-326.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. *Annual review of Ecology, Evolution and Systematics* 37: 637-669.

Peng, L., Lu, C., Huang, S., Guo, P. & Zhang, Y. 2014. A new species of the genus *Thermophis* (Serpentes: Colubridae) from Shangri-La, Northern Yunnan, China, with a proposal for an eclectic rule for species delimitation. *Asian Herpetological Research* 5(4): 228-239.

Phillips, B.L., Brown, G.P. & Shine, R. 2003. Assessing the potential impact of cane toads on Australian snakes. *Conservation Biology* 17: 1738-1747.

Platenberg, R.J. & Harvey, D.S. 2010. Endangered species and land use conflicts: a case study of the Virgin Islands Boa (*Epicrates granti*). *Herpetological Conservation and Biology* 5 (3): 548-554.

Plummer, M.V. 1997. Population ecology of green snakes (*Opheodrys aestivus*) revisited. *Herpetological Monographs* 11: 102-123.

Pomara, L., Ledee, O.E., Martin, K.J. & Zuckerberg, B. 2014. Demographic consequences of climate change and land cover help explain a history of extirpations and range contraction in a declining snake species. *Global Change Biology* 20: 2087-2099. doi:10.1111/gcb.12510.

Powell, R. & Henderson, R.W. 2005. Conservation status of Lesser Antillean reptiles. *Iguana* 12 (2): 63-77.

Purvis, A., Gittleman, J.L., Cowlishaw, G. & Mace, G.M. 2000. Predicting extinction risk in declining species. *Proceedings of the Royal Society, London* 267: 1947-1952.

Pyron, R.A. & Burbrink, F.T. 2009. Systematics of the common king snake (*Lampropeltis getula*; Serpentes; Colubridae) and the burden of heritage in taxonomy. *Zootaxa* 2242: 22-32.

Pyron, R.A. & Burbrink, F.T. 2011. Extinction, ecological opportunity, and the origins of global snake diversity. *Evolution* 66: 163-178. doi:10.1111/j.1558-5646.2011.01437.x

Pyron, R.A. 2014. Temperate extinction in squamate reptiles and the roots of latitudinal diversity gradients. *Global Ecology and Biogeography* 23: 1126-1134. doi:10.1111/geb.12196

Quintero-Ángel, A., Osorio-Dominguez, D., Vargas-Salinas, F. & Saavedra-Rodriguez, C.A. 2012. Roadkill rate of snakes in a disturbed landscape of Central Andes of Colombia. *Herpetology Notes* 5: 99-105.

Rainwater, T.R., Reynolds, K.D., Cańas, J.E., Cobb, G.P., Anderson, T.A., McMurry, S.T. & Smith, P.N. Organochlorine pesticides and mercury in cottonmouths (*Agkistrodon piscivorus*) from north-eastern Texas, USA. *Environmental Toxicology and Chemistry* 24 (3): 665-673.

Raxworthy, C.J. & Nussbaum, R.A. 2000. Extinction and extinction vulnerability of amphibians and reptiles in Madagascar. *Amphibian and Reptile Conservation* 2 (1): 15-23.

Reading, C.J., Luiselli, L.M., Akani, G.C., Bonnet, X. Amori, G., Ballouard, J.M., Filippi, E., Naulleau, G., Pearson, D. & Rugiero, L. 2010. Are snake populations in widespread decline? *Biology Letters* 6: 777-780. doi:10.1098/rsbl.2010.0373

Reber, D.L. & Reber, A.S. 1996. Rattlesnake roundup in Kansas: a brief history. *Amphibian & Reptile Conservation* 1 (1): 10-14.

Reed, D.H. 2003. Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. *Biological Conservation* 113: 23-34.

Reed, R.N. & Shine, R. 2002. Lying in wait for extinction: ecological correlates of conservation status among Australian elapid snakes. *Conservation Biology* 16 (2): 451-461.

Reeder, T.W., Townsend, T.M., Mulcahy, D.G., Noonan, B.P., Wood, P.L. Jr, Sites, J.W. Jr & Wiens, J.J. 2015. Integrated analyses resolve conflicts over squamate reptile phylogeny and reveal unexpected placements for fossil taxa. *PLoS One* 10 (3): e0018199. doi:10.1371/journal.pone.0118199

Ribeiro, R., Santos, X., Sillero, N., Carretero, M.A. & Llorente, G.A. 2009. Biodiversity and land uses: is agriculture the biggest threat in reptiles' assemblages? *Acta Oecologica* 35: 327-334.

Rodda, G.H. 1992. Loss of native reptiles associated with introductions of exotics in the Mariana Islands. *Pacific Science* 46: 399-400.

Rodrigues, M.T. 2005. The conservation of Brazilian reptiles: challenges for a megadiverse country. *Conservation Biology*. 19: 659-664.

Roe, J.H., Kingsbury, B.A. & Herbert, N.R. 2004. Comparative water snake ecology: conservation of mobile animals that use temporally dynamic resources. *Biological Conservation* 118: 79-89.

Roe, J.H., Gibson, J. & Kingsbury, B.A. 2006. Beyond the wetland border: estimating the impact of roads on two species of water snakes. *Biological Conservation* 130: 161-168. doi:10.1016/j.biocon.2005.12.010

Roe, J.H., Attum, O. & Kingsbury, B.A. 2013. Vital rates and population demographics in declining and stable watersnake populations. *Herpetological Conservation and Biology* 8 (3): 591-601.

Rohr, J.R. & Palmer, B.D. 2013. Climate change, multiple stressors and the decline of ectotherms. *Conservation Biology* 27 (4): 741-751. doi:10.1111/cobi.12086.

Rose, W. 1950. The reptiles and amphibians of southern Africa. Maskew Miller, Cape Town.

Rosen, P.C. & Lowe, C.H. 1994. Highway mortality of snakes in the Sonoran Desert of southern Arizona. *Biological Conservation* 68: 143-148.

Row, J.R., Blouin-Demers, G. & Weatherhead. P.J. 2007. Demographic effects of road mortality in black ratsnakes (*Elaphe obsoleta*). *Biological Conservation* 137: 117-124. doi:10.1016/j.biocon.2007.01.020

Ryan, T.J., Philippi, T., Leiden, Y.A., Dorcas, M.E., Bently Wigley, T. & Gibbons, J.W. 2002. Monitoring herpetofauna in a managed forest landscape: effect of habitat types and census techniques. *Forest Ecology and Management* 167: 83-90.

Santos, X., Brito, J.C., Pleguezuelos, J.M. & Llorente, G.A. 2007. Comparing Filippi and Luiselli's (2000) method with a cartographic approach to assess the conservation status of secretive species: the case of the Iberian snake-fauna. *Amphibia-Reptilia* 28: 17-23.

Santos, X. & Llorente, G.A. 2009. Decline of a common reptile: case study of the viperine snake *Natrix maura* in a Mediterranean wetland. *Acta Herpetologica* 4 (2): 161-169.

Schlaepfer, M.A., Hoover, C. & Dodd, C.K. Jnr. 2005. Challenges in evaluating the trade in amphibians and reptiles on wild populations. *Bioscience* 55: 256-264.

Seburn, D. & Seburn, C. 2000. Conservation priorities for the amphibians and reptiles of Canada. World Wildlife Fund Canada and Canadian Amphibian and Reptile Conservation Network.

Secretariat of the Convention on Biological Diversity. 2014. Global Biodiversity Outlook 4. 155pp.

Segniagbeto, G.H., Petrozzi, F., Aïdam, A. & Luiselli, L. 2013. Reptiles traded in the fetish market of Lomé, Togo (West Africa). *Herpetological Conservation and Biology* 8 (2): 400-408.

Seigel, R.A., Gibbons, J.W. & Lynch, T.K. 1995. Temporal changes in reptile populations: effects of a severe drought on aquatic snakes. *Herpetologica* 51: 424-434.

Seigel, R.A., Shiel, C.A. & Doody, J.S. 1998. Changes in a population of endangered rattlesnakes *Sistrurus catenatus* following a severe flood. *Biological Conservation* 83: 127-131.

Sewell, D., Guillera-Arroita, Griffiths, R.A. & Beebee, T.J.C. 2012. When is a species declining? Optimizing survey effort to detect population changes in reptiles. *PLoS ONE* 7: e43387

Shaffer, H.B., Fisher, R.N. & Davidson, C. 1988. The role of natural history collections in documenting species declines. *TREE* 13 (1): 27-30.

Sharma, D. S. K. 1999. Tortoise and freshwater turtle trade and utilisation in Peninsular Malaysia. A TRAFFIC Southeast Asia report, Malaysia.

Shine, R. 1991. Australian snakes – a natural history. Reed New Holland.

Shine, R., Harlow, P. & Keogh, J.S. 1995. Biology and commercial utilisation of acrochordid snakes, with special reference to the karung (*Acrochordus javanicus*). *Journal of Herpetology*. 29: 352-360.

Smith, M.J., Cogger, H., Tiernan, B., Maple, D., Boland, C., Napier, F., Detto, T. & Smith, P. 2012. An oceanic island reptile community under threat: the decline of reptiles on Christmas Island, Indian Ocean. *Herpetological Conservation and Biology* 7 (2): 206-218.

Spawls, S., Howell, K., Hinkel, H. & Menegon, M. 2018. Field Guide to East African Reptiles, 2nd Edition. Bloomsbury. 624pp.

Steen, D.A. 2010. Snakes in the grass: secretive natural histories defy both conventional and progressive statistics. *Herpetological Conservation and Biology* 5 (2): 183-188.

Steen, D.A., Osborne, P.A., Dovčiak, M., Patrick, D.A. & Gibbs, J.P. 2015. A preliminary investigation into the short-term effects of a prescribed fire on habitat quality for a snake assemblage. *Herpetological Conservation and Biology*. 10 (1): 263-272.

Sterijovski, B., Ajtic, R., Tomovic, L. & Bonnet, X. 2014. Conservation threats to dice snakes (*Natrix tessellata*) in Golem Grad Island (FYR of Macedonia). *Herpetological Conservation and Biology* 9 (3): 468-474.

Stevenson, D.J., Enge, K.M., Carlile, L.D., Dyer, K.J., Norton, T.M., Hyslop, N.L. & Kiltie, R.A. 2009. An eastern indigo snake (*Drymarchon couperi*) mark-recapture study in south-eastern Georgia. *Herpetological Conservation and Biology* 4 (1): 30-42.

Stevenson-Hamilton, J. 1947. Wild Life in South Africa. Cassell and Company, Ltd.

Streicher, J.W. & Wiens, J.J. 2016. Phylogenomic analyses reveal novel relationships among snake families. *Molecular Phylogenetics and Evolution*. 100: 160-169. doi:10.1016/j.ympev.2016.04.015

Sztencel-Jablonka, A., Mazgajski, T.D., Bury, S., Najbar, B., Rybacki, M., Bogdanowicz, W. & Mazgajska, J. 2015. Phylogeography of the smooth snake *Coronella austriaca* (Serpentes: Colubridae): evidence for a reduced gene pool and a genetic discontinuity in Central Europe. *Biological Journal of the Linnean Society*. (Need complete citation)

Tetzlaff, S., Allender, M., Ravesi, M., Smith, J. & Kingsbury, B. 2015. First report of snake fungal disease from Michigan, USA involving Massasaugas, *Sistrurus catenatus* (Rafinesque 1818). *Herpetology Notes* 8: 31-33.

Thompson, M.E., Halstead, B.J., Wylie, G.D., Amarello, M., Smith. J.J., Casazza, M.L. & Routman, E.J. 2013. Effects of prescribed fire on *Coluber constrictor Mormon* in coastal San Mateo County, California. *Herpetological Conservation and Biology* 8 (3): 602-615.

Tolley, K.A., Alexander, G.J., Branch, W.R., Bowles, P. & Maritz, B. 2016. Conservation status and threats for African reptiles. *Biological Conservation*. 204: 63-71. doi:10.1016/j.biocon.2016.04.006

Tuberville, T.D., Bodie, J.R., Jensen, J.B., La Claire, L.V. & Gibbons, J.W. 2000. Apparent decline of the southern hognose snake (*Heterodon simus*). *Journal of Elisha Mitchell Scientific Society* 116 (1): 19-40.

Ujvari, B., Brown, G., Shine, R. & Madsen, T. 2016. Floods and famine: climate-induced collapse of a tropical predator-prey community. *Functional Ecology* 30: 453-458. doi:10.1111/1365-2435.12505

Valkonen, J.K. & Mappes, J. 2014. Resembling a viper: implications of mimicry for conservation of the endangered smooth snake. *Conservation Biology* 1-7. doi:10.1111/cobi.12368

Vitt. L. J., Caldwell, J. P., Wilber, H. M. & Smith, D. C. 1990. Amphibians and harbingers of decay. *BioScience* 40:418.

Watson, J.E.M., Shanahan, D.F., Di Marco, M., Allan, J., Laurance, W.F., Sanderson, E.W., Mackey, B. & Venter, O. 2016. Catastrophic declines in wilderness areas undermine global environment targets. *Current Biology* 26 (21): 2929-2934. doi:10.1016/j.cub.2016.08.049

Weatherhead, P.J., Blouin-Demers, G. & Prior, K.A. 2002. Synchronous variation and long-term trends in two populations of black rat snakes. *Conservation Biology* 16 (6): 1602-1608.

Webb, J.K., & Shine, R. 1998. Ecological characteristics of a threatened snake species, *Hoplocephalus bungaroides* (Serpentes: Elapidae). *Animal Conservation* 1: 185-193.

Webb, J.K., Brook, B.W. & Shine, R. 2002. Collectors endanger Australia's most threatened snake, *Hoplocephalus bungaroides*. *Oryx* 36: 170-181.
Whelan, R. J. 1995. The ecology of fire. Cambridge University Press, Melbourne, Australia.
Whitfield, S.M., Reider, K., Greenspan, S. & Donnelly, M.A. 2014. Litter dynamics regulate population densities in a declining terrestrial herpetofauna. *Copeia* 2014 (3): 454-461. doi:10.1643/CE-13-061
Willson, J.D., Winne, C.T., Dorcas, M.E. & Gibbons, J.W. 2006. Post-drought response of semi-aquatic snakes inhabiting an isolated wetland: insights on different strategies for persisting in a dynamic habitat. *Wetlands* 26: 1071-1078.
Wilson, L.& McCranie, J.R. 2003. The conservation status of the herpetofauna of Honduras. *Amphibian and Reptile Conservation* 3 (1): 6-33.
Wilson, S. & Swan. G. 2003. A complete guide to reptiles of Australia. Reed New Holland.
Wingate, L. 1967. Snakes alive! Howard Timmins, Cape Town.
Wittenberg, R.D. 2012. Foraging ecology of the timber rattlesnake (*Crotalus horridus*) in a fragmented agricultural landscape. *Herpetological Conservation and Biology* 7 (3): 449-461.
Woinarksi, J. C. Z., Murphy, B. P., Palmer, R., Legge, S. M., Dickman, C. R., Doherty, T. S., Edwards, G., Nankivell, A., Read, J. L. & Stokeld, D. 2018. How many reptiles are killed by cats in Australia? *Wildlife Research* 45 (3): 247-266.
WWF Living Planet Report 2014. https://www.worldwildlife.org/pages/living-planet-report-2014. Downloaded November 2018.
Wykes, A. Snake Man. 1960. Hamish Hamilton.
Zhou, Z. 1998. The China Red Data Book of Endangered Animals – Amphibia and Reptilia
Zhou, Z. & Jiang, Z. 2004. International trade status and crisis for snake species in China. *Conservation Biology* 18 (5): 1386-1394.

CHAPTER 2

Global snake diversity, systematics and conservation: A review

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Formatted as a manuscript for submission to an international peer review journal

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Running header: Global snake diversity, systematics and conservation

2.1 ABSTRACT

Snakes (Class Reptilia, Order Squamata, Suborder Serpentes) play an important role in terrestrial ecosystems as predator and prey. Snake diversity has increased significantly in recent decades because of intensified exploration and research, as well as increased use of molecular techniques in systematics and taxonomy. Biologists have raised recent conservation concern following several documented reports of reptile population declines from geographically widespread localities across the globe. Snakes feature prominently in human-wildlife conflict and snakebite was recently added by the World Health Organisation under the category of neglected tropical diseases. They are also heavily utilised in many regions for food, fashion and traditional medicine. This paper reviews the current understanding of global snake diversity, systematics and conservation.

Key words: Snake diversity; systematics; taxonomy; conservation.

2.2 INTRODUCTION

Snakes (Class Reptilia, Order Squamata, Suborder Serpentes) induce fear and fascination. They feature prominently in folklore, religion and culture, from the rainbow serpents of Australian Aboriginal folklore, perpetuated to live in billabongs during the dry season and bring rain in the wet season, using their massive bodies to carve out rivers (Shine, 1988), to Aesculapius, the Greek god of medicine, which today is incapsulated in the medical symbol portraying a snake intertwined on a staff (Schmidt & Inger, 1957).

Snakebite envenomation in humans is estimated between 1.8 million to 5.4 million people annually resulting in severe socio-economic impacts (Fry, 2018). In India, an estimated 49 000 people die annually from snakebite (Bawaskar et al., 2017). In response to this global

pandemic, the World Health Organisation re-listed snakebite under Category A of Neglected Tropical Diseases on June 9th, 2017 (Chippaux, 2017).

Snakes are also heavily utilised as a food resource globally, especially in tropical regions of the world. Likewise, snakeskins are used in the manufacture of fashion accessories such as handbags, belts, wallets and shoes, including use in traditional medicine (Segniagbeto et al., 2013). Zhou & Jiang (2004) estimated that 2,478,540 live snakes and 6,418,938 individual snake skins were exported from China between 1990 to 2001. In another study in Cambodia, an estimated 2.7 to 12.2 million snakes are harvested annually for use as crocodile fodder on commercial crocodile farms. These mostly comprise semi-aquatic or aquatic snakes of the family Homalopsidae (Brooks et al., 2010). Rattlesnake roundups are still popular in several states in the United States. One study found that Eastern Diamondback Rattlesnakes *Crotalus adamanteus* have declined in numbers as well as average size during surveys spanning two decades (Means, 2009).

A combination of habitat loss, environmental degradation, pollution, persecution, unsustainable exploitation and invasive species has led to population declines in many snake species, raising conservation concern (Gibbons et al., 2000; Reading et al., 2010). In addition, an emerging snake fungal disease *Ophiomyces ophiodiicola* has negatively impacted snakes in North America and was recently detected in wild European snakes (Allender et al., 2015; Franklinos et al., 2017).

A paradox to snake population declines is the dramatic increase in documented species diversity over the last two decades. No less than 591 species have been described as new to science post-2000. This is almost certainly due to increased survey effort into previously unexplored or inaccessible regions, in addition to the increased use of molecular techniques to define species boundaries and identify cryptic lineages (references in this study).

An underlying tenet in biodiversity conservation is understanding species diversity and having, or procuring, up-to-date species lists based on sound taxonomy. This allows assessment of the conservation status of individual species, as well as the ecosystems and species composition in which those species occur. As snakes play a pivotal role in ecosystems both as predator on numerous invertebrate and vertebrate organisms and in turn, as prey consumed by other predators, a fundamental understanding of their diversity and population dynamics is crucial to understanding their role and influence on ecosystem functioning. We reviewed the current understanding of global snake diversity, systematics and conservation given the many factors affecting biodiversity globally.

2.3 METHODS

The author (WRS) has kept a species list of extant snakes since 2010 (adapted from Mattison, 1999) in Excel spreadsheet format which is periodically updated as new taxonomic revisions and species descriptions were published and accessed. In January 2017, this list was cross-referenced with the online The Reptile Database http://www.reptile-database.org which is referenced by many recent authors (i.e. Broadley et al., 2018; Leviton et al., 2018) and deemed a reliable online resource. More recently, the list was cross-referenced and updated shortly after the release of Version 1.0 (3 July 2018) (Uetz, P., Freed, P. & Hošek, J (eds), The Reptile Database, http://www.reptile-database.org [accessed 3 July 2018]). The author's list generally concurs with that of The Reptile Database, although there are several minor differences which does not impact on the current study. It must be acknowledged that systematics, taxonomy and new species descriptions is ongoing as new information comes to light, therefore the stated figures given in this study are by no means precise and open to interpretation.

The conservation status of each species was referenced against the IUCN Red List (where listed) www.iucnredlist.org . Only species listed in the higher threat categories are

discussed below. These include '*Extinct*'. '*Critically Endangered*', '*Endangered*' and '*Vulnerable*'. These are summarised in Table S2.1. The IUCN Red List was accessed during August 2018 (The IUCN Red List of Threatened Species Version 2018-1) using several search criteria. See also Wallach et al. (2014) for a comprehensive list of snake species of the world.

Higher-level snake taxonomy used in this study follows that of Figueroa et al. (2016), with the addition of the recently described Lamprophiid subfamily Cyclocorinae from the Philippines (Weinell & Brown, 2018). (See also Pyron et al., 2013; Streicher & Wiens, 2016; for comparative higher-level snake phylogenies.)

2.4 RESULTS

2.4.1 Subspecies

The recognition of subspecies has been a contentious issue between reptile taxonomists with numerous recent revisions either synonymising some or elevating others to full species rank, often aided by molecular analyses. (For recent African snake revisions where former subspecies have been given specific rank, see Broadley, 2002; Broadley & Wüster, 2004; Trape et al., 2009; Broadley et al. 2018; Wüster et al. 2018.)

In the present study, we have included recognised subspecies in the analyses to evaluate overall species diversity. Considering the above, many of these 'subspecies' may receive full species status in future revisionary studies and the increased use of molecular techniques in defining species boundaries. A concerted effort was made to only include generally accepted subspecies as defined in authoritative regional field guides and peer-reviewed species inventories, review papers and regional checklists published in academic journals. The IUCN Red List generally includes species only in the conservation assessments, but does however, make mention of recognised subspecies under the individual species account.

Despite the trend towards recognising full species through the evolutionary species concept, some authors have argued for the retention of subspecies under certain circumstances. For a full discussion, see Hawlitschek et al. (2012). A critique of subspecies based on colour pattern and variation in North American rat snakes was discussed by Burbrink, Lawson & Slowinski (2000).

2.4.2 Taxonomic vandalism

The issue of taxonomic vandalism has been debated extensively (Kaiser et al., 2013) and must be addressed accordingly. Taxonomic vandalism occurs when species are described in non-peer-reviewed, often self-published journals without robust sampling or rigorous statistical analyses. Molecular sequence data is often lacking (although not crucial to a species description) and 'novel species' are described based on putative differences in colour and external morphology only. These publications may be widely disseminated and end up in conservation departments or scientific institutions and taken as factual. This can lead to incorrect names entering species inventories and causing confusion between taxonomists and conservationists and duplicate species then having to be clarified or synonymised in future revisions. Much valuable time is wasted by counteracting and refuting such works. This may potentially hamper conservation efforts. For a full discussion on science-based taxonomy and conservation, see Thomson et al. (2018). It is recommended that conservation biologists collaborate with taxonomists, or reference peer-reviewed journals only, to ensure that they are using the correct and most up-to-date taxonomy when compiling reports or drafting species management plans, including the production of regional field guides, which are used extensively by field workers as reference material.

2.4.3 Snake diversity, systematics and conservation

This present study identified approximately 3 750 extant snake species and a total 4 445 snake taxa (species *and* recognised subspecies) (Table S2.1). Of note, is that no less than 591 taxa have been described post-2000 (Figure 2.1). When data were compared approximately every two decades, the only other notable period historically where more taxa were described was between 1860 to 1879 (638 species). This was largely due to the work of several distinguished herpetologists at the time, most notably the American palaeontologist and herpetologist Edward Drinker Cope (149 taxa); Albert Karl Günther, a German-born British herpetologist later based at the British Museum (147 taxa); Wilhelm Peters, a German naturalist and explorer (93 taxa) and the Italian taxonomist, zoologist and herpetologist Giorgio Jan (77 taxa) (WRS unpublished data).

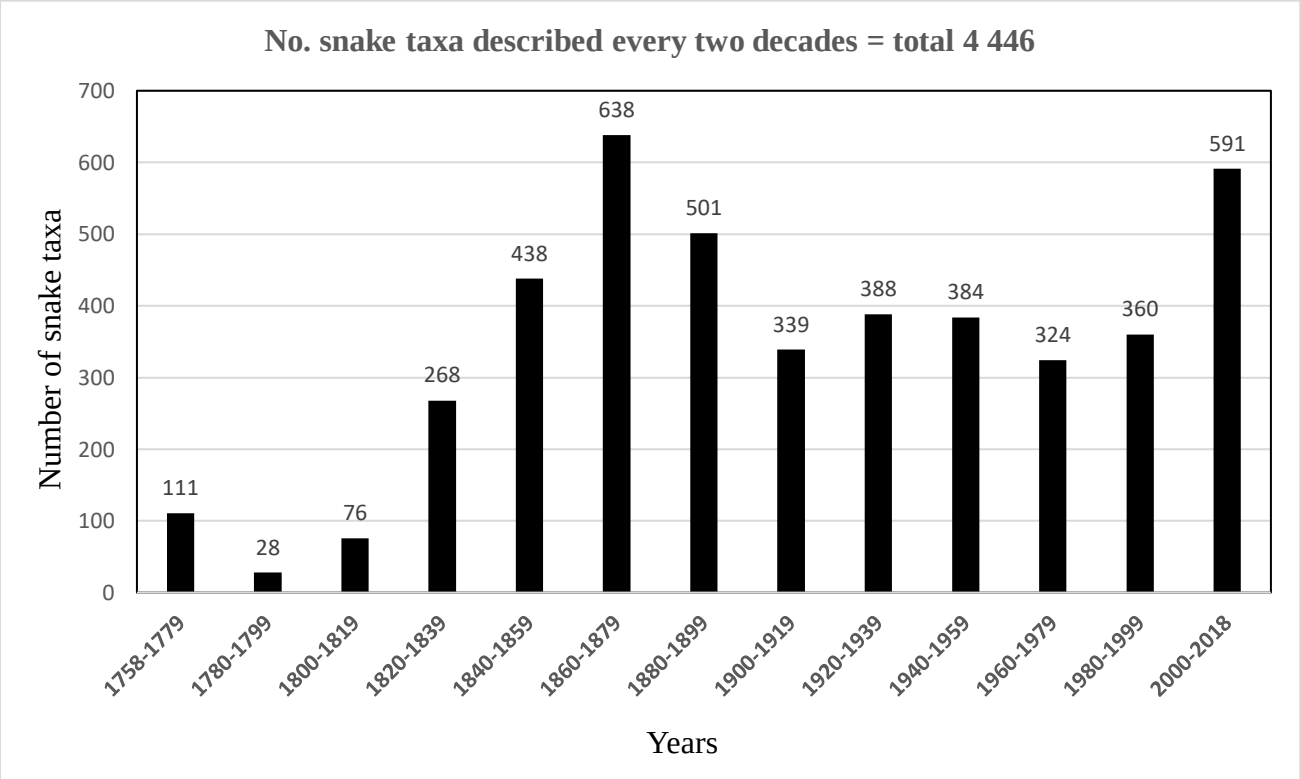

Figure 2.1: Number of snake taxa described approximately every two decades from 1758 – 2018.

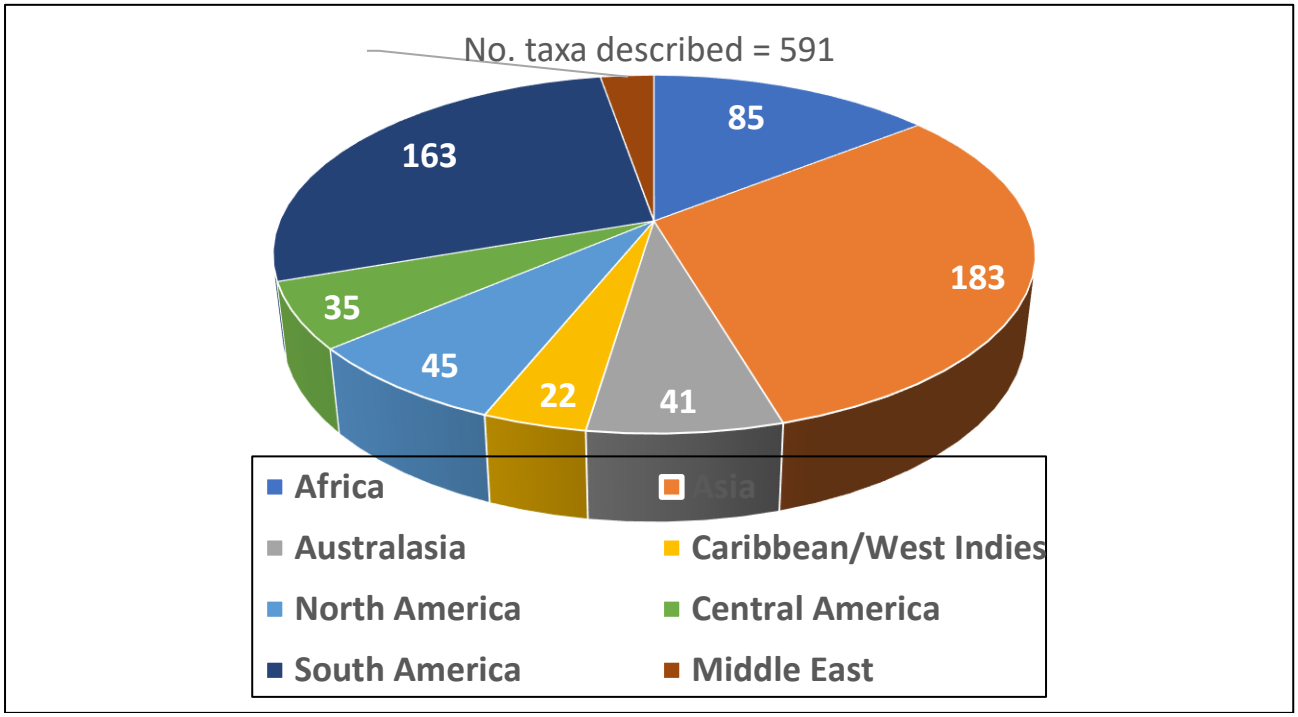

Figure 2.2: Snake taxa described post-2000 from global regions. (The one European species is not shown).

The high number of snake species descriptions post-2000 can be attributed to two factors: 1 -Exploration and access into previously unexplored or previously difficult to access regions and countries. 2 – Increased use of molecular techniques to define species boundaries and the subsequent discovery or confirmation of 'cryptic' species. A pie chart (Figure 2.2) indicating the global regions from where recent (post-2000) species have been described emphasises this. The highest figure was from Asia (183 taxa), where increased exploration into regions such as Vietnam, have yielded numerous species new to science. This was followed by South America with 163 taxa, mostly from Brazil, Venezuela and Colombia. The 45 taxa described from North America mostly stem from Mexico (in this study included as part of North America and not Central America.) Surprisingly, Africa lags Asia and South America with only 85 recently described taxa. However, increased surveys to countries such as Angola, Mozambique, Sudan, Ethiopia and the Democratic Republic of Congo are revealing new

species, notwithstanding recent revisions which have identified numerous cryptic species, such as in the wide-ranging egg-eating snakes *Dasypeltis*, where nine cryptic taxa have been formally described (Trape & Mané, 2006; Saleh & Sarhan, 2016; Bates & Broadley, 2018), house snakes *Boaedon* (Greenbaum et al. 2015; Trape & Mediannikov, 2016), as well as the forest cobra *Naja (Boulengerina) melanoleuca* which is now split into five species (Ceriaco et al., 2017; Broadley et al., 2018). Only one European species, *Vipera walser*, has been described in the last two decades and not included in the pie chart (Ghielmi et al., 2016).

2.4.4 Conservation Status

Of the 3 750 identified snake species reviewed in this paper, five species have been identified as Extinct by the IUCN. All five were island-dwelling forms and include *Typhlops cariei (=Madatyphlops cariei)* from Mauritius; *Bolyeria multocarinata* from Round Island north-east of Mauritius; *Alsophis antiguae* from Antigua and Barbuda; *Clelia errabunda* from Saint Lucia and *Erythrolamprus perfuscus* from Barbados. At least four of the above species are believed to have been driven to extinction through the introduction of invasive species into their island habitat (IUCN Red List, 2018).

Of the snake species, 57 (1.5%) are listed as Critically Endangered and include 33 species restricted to islands, 21 from continental landmasses, one distributed over islands and continent and two sea snakes (Table S2.1). A total of 117 species (3.1%) are listed as Endangered and include 50 species confined to islands, 65 species to continental landmasses, one on both and one sea snake (Table S2.1). A total of 111 (3.0%) species are listed as Vulnerable and include 36 species confined to islands, 67 species to continental landmasses, five species on both islands and continents and three sea snakes (Table S2.1). A further 95 species are listed as Near Threatened, with 441 species as Data Deficient and 1 341 species as Least Concern. Approximately 1 583 species have not yet been assessed by the IUCN (IUCN Red List, 2018).

2.4.5 Scolecophidians – The Superfamily Typhlopoidea

This group of snakes is primarily fossorial and forms a basal clade to the Alethinophia (Henophidia and Caenophidia) (Broadley & Wallach, 2009; Figueroa et al., 2016).

2.4.6 Family: Anomalepididae

A poorly-known family of fossorial blind snakes from Central and South America consisting of approximately 18 species in 4 genera. Due to their fossorial lifestyles, their conservation status is largely unknown, but they may be vulnerable to deforestation in some parts of their range (Broadley & Wallach, 2009). Note: Miralles et al. (2018) found the scolecophidians to be paraphyletic when the Anomaledidae were included.

2.4.7 Family: Leptotyphlopidae

Small fossorial snakes which feed on termite and ant eggs and larvae, commonly referred to as thread or blind worm snakes. The family was reviewed by Adalsteinsson et. al. (2009), who identified two major clades – the New World Epictinae and Old World Leptotyphlopinae. They include approximately 141 species in 13 genera. Due to their fossorial lifestyles, their conservation status and population dynamics are largely unknown, but some have very restricted ranges and may be at risk due to habitat loss, particularly forest-dwelling species. Three *Mitophis spp*. from the Caribbean are listed as Critically Endangered as well as *Tetracheilostoma carlae*. A further two species are listed as Endangered: *Mitophis pyrites* and *Tetracheilostoma breuili* (Table S2.1).

2.4.8 Family: Gerrhopilidae

A small family of Asian blind snakes previously included in the Typhlopidae. There are 22 species in two genera. There conservation status is largely unknown.

2.4.9 Family: Xenotyphlopidae

This family is restricted to northern Madagascar and represented by one Critically Endangered species *Xenotyphlops grandidieri*, which is reportedly only known from two specimens. It was placed in its own monotypic family based on its relatively broad, oval-shaped rostral scale with near vertical lateral profile and single, large cloacal shield which differs from most other scolecophidians (Pyron & Wallach, 2014). A second species, *Xenotyphlops mocquardii*, was described by Van Wallach et al. (2007), but was subsequently synonymised with *Xenotyphlops grandidieri*, once again rendering the family monotypic.

2.4.10 Family: Typhlopidae

A large and diverse family of fossorial blind snakes with smooth polished scales and enlarged rostral shields facilitating their subterranean existence. Four subfamilies are recognised: *Typhlopinae* (American blind snakes); *Asiatyphlopinae* (Australasian blind snakes); *Afrotyphlopinae* (African blind snakes) and *Madatyphlopinae* (Madagascan blind snakes). The family was reviewed by Blair Hedges et al. (2014), and Pyron and Wallach (2014). The conservation status of this family is difficult to assess due to their subterranean lifestyles. However, several island forms from the Caribbean and West Indies are listed as Critically Endangered and Endangered (Table S2.1). The Tanzanian endemic *Afrotyphlops geirrai*, which inhabits the Usambara and Uluguru Mountains, is listed as Endangered. *Typhlops cariei (=Madatyphlops?)* from Mauritius is listed as Extinct and based on recent fossil records. Its generic placement is uncertain (Pyron & Wallach, 2014).

2.4.11 Superfamily Henophidia

The taxonomy and relationships between the various Henophidian families is not fully resolved but includes the pythons and boas (also placed in the Superfamily Booidea). The synopsis below includes the pythons, boas and relatives. Note: The Henophidia, as defined here, is not considered monophyletic.

2.4.12 Family: Aniliidae

The South American pipe snakes form a monotypic family restricted to the Amazon basin, South America (Mattison, 1995). *Anilius scytale* is a brightly coloured fossorial snake with a cylindrical body. It has a wide distribution and therefore not considered threatened.

2.4.13 Family: Tropidophiidae

Commonly referred to as wood snakes, this family includes 34 species in two genera. They are distributed in South and Central America and the West Indies islands. Many of the island forms may be threatened, *Tropidophis hendersoni* is listed as Critically Endangered. For further details regarding the taxonomy and phylogeny of this family refer to Wilcox et al. (2002).

2.4.14 Family: Bolyeriidae

The Round Island boas comprise two species in two genera only found on Round Island north-east of Mauritius in the Indian Ocean. Their taxonomy and evolutionary history are not well understood, but they are believed to be allied to the Family Xenophidiidae of Asia. *Bolyeria multocarinata* is presumed extinct as recent intensive searches on Round Island have failed to locate this species. *Casarea dussumieri* has been a flagship species in snake conservation and has been successfully maintained and bred in captivity at the Jersey Zoo (Jersey Wildlife Preservation Trust) in the Channel Islands. *Casarea dussumieri* is listed as Endangered. Invasive goats and rabbits have been removed from Round Island and rehabilitation is ongoing (Mattison, 1995; Pyron et al., 2014; Jersey Wildlife Preservation Trust online resources).

2.4.15 Family: Xenophidiidae

This family has two species in one genus, *Xenophidion acanthognathus* and *Xenophidion schaeferi*. They are found in Borneo and Peninsula Malaysia (Figueroa et al., 2016). These two species are not listed as threatened.

2.4.16 Superfamily: Booidea

A taxonomic revision of this Superfamily was undertaken by Pyron et al. (2014), who recognised the families Calabariidae, Candoiidae, Sanziniidae, Charinidae, Erycidae and Boidae, listed below. (See also Reynolds and Henderson, 2018).

2.4.17 Family: Calabariidae

A monotypic family restricted to West and Central tropical Africa (Chippaux, 2006). Females are oviparous laying 1-4 large eggs. *Calabaria reinhardtii* are secretive and seldom observed snakes, therefor their conservation status is not well understood. However, they have a wide distribution range in forested regions of tropical west and central Africa.

2.4.18 Family: Candoiidae

The Pacific boas (*Candoia*) include five species in one genus and confined to New Guinea and neighbouring islands (Mattison, 1995). At least one species occurs as far as the Tokelau Islands. Although not currently listed under a threatened category, they often feature in the pet trade and some species may be vulnerable to exploitation and habitat destruction.

2.4.19 Family: Sanziniidae

This family includes four species in two genera confined to Madagascar (Pyron et al., 2014). Surprisingly, none are listed under a threatened category, despite numerous Madagascan snakes being seriously threatened (see the Pseudoxyrhophiinae account below). They are frequently bred in captivity.

2.4.20 Family: Charinidae

This North and Central American family is divided into two subfamilies, the Charininae with four species in two genera and the Ungaliophiinae with three species in two genera. None are listed as threatened (Pyron et al., 2014).

2.4.21 Family: Erycidae

The sand boas are found in North Africa, eastern Europe, Arabia, the Middle East and Asia and comprise approximately 12 species with numerous putative subspecies. Generally placed in

one genus, *Eryx*, some authors recognise a second genus *Gongylophis*. None are considered threatened, but their taxonomy and conservation status are in need of review.

2.4.22 Family: Boidae

The true boas include approximately 32 species and several subspecies in five genera. This family is restricted to Central and South America, with some species occurring on Cuba and other Caribbean islands. The taxonomy has undergone several revisions, for example, Pyron et al. (2014), revised all species included in the Superfamily Booidea, including Boidae, Calabariidae, Candoiidae, Charinidae, Erycidae and Sanziniidae. Reynolds et al. (2013), examined the molecular phylogeny and historical biogeography of the West Indian genus *Chilabothrus*, some of which are highly threatened, including *Chilabothrus argentum* (Critically Endangered), *C. granti* and *C. monensis* (Endangered) and *C. exsul* and *C. subflavus* (Vulnerable). Several other boid species are listed as Endangered or Vulnerable, particularly island forms with restricted ranges (Table S2.1).

2.4.23 Superfamily: Uropeltoidea

This family of unusual snakes is sometimes included within the greater Henophidia. They are found in Asia and include three families:

2.4.24 Family: Cylindrophiidae

Asian pipe snakes are found in India and surrounding regions. There is one genus *Cylindrophis* with approximately 14 species. None are currently listed as threatened.

2.4.25 Family: Anomochilidae

The dwarf pipe snakes are confined to rainforest in Sumatra (Mattison, 1995). There is one genus with three species and their conservation status is largely unknown.

2.4.26 Family: Uropeltidae

The shield-tailed snakes are a family of fossorial snakes with rigid skull and jaws. They have unusual tails adorned with rough scales or covered with spines or tubercles. Approximately 59

species in eight genera. At least two species are Endangered – *Platyplectrurus madurensis* and *Rhinophis travancoricus*, both from the Western Ghats in India. *Melanophidium bilineatum* and *Uropeltis phipsonii* are Vulnerable (Table S2.1).

2.4.27 Superfamily: Pythonoidea

2.4.28 Family: Xenopeltidae

A family of two species in one genus (*Xenopeltis hainanensis* and *X. unicolor*) from China and south-east Asia (Mattison, 1995). Nocturnal snakes with cylindrical bodies and smooth, polished, highly iridescent scales giving rise to their colloquial name of sunbeam snakes. The two species are listed as Least Concern.

2.4.29 Family: Loxocemidae

A monotypic family containing only *Loxocemus bicolor* from Mexico and the northern parts of Central America (Mattison, 1995). Semi-fossorial and largely nocturnal, females are oviparous. This species is not listed under any threatened category.

2.4.30 Family: Pythonidae

The true pythons are a well-known clade of constrictors found from Africa, through Asia and into Australia, which has a high diversity of species. There are approximately 40 species in seven genera. The family has undergone many revisions over the preceding decades. Despite heavy exploitation across their range, surprisingly few species are listed under threatened categories. *Aspidites ramsayi* from Australia was previously listed as Endangered, but in version 3.1 of the IUCN Red List it has been downgraded to Least Concern (IUCN Red List 2018). *Python bivittatus bivittatus* and *P. kyaiktiyo* from Asia are listed as Vulnerable. Incidentally, *P. bivittatus* has become a highly successful invasive species in Florida, USA, despite an estimated decline of 30% across its natural range over the last decade (IUCN, 2018). The trade in pythons is regulated by CITES, however, careful monitoring of species should continue to evaluate the impact of trade and exploitation.

Caenophidia

2.4.31 Superfamily: Acrochordoidea

2.4.32 Family: Acrochordidae

The aquatic file snakes are a family of three species in one genus distributed from northern Australia northward into Indonesia, Malaysia, southern Asia and westward to India. They are highly aquatic occurring in fresh and brackish water. These snakes are heavily exploited for food and skins across their range, yet, despite intense harvesting, they are listed as Least Concern by the IUCN (Shine, 2003).

2.4.33 Superfamily: Colubroidea

This superfamily comprises most snake families and are considered to be the most evolutionary derived and modern snakes (Figueroa et al., 2016; Streicher & Wiens, 2016).

2.4.34 Family: Xenodermidae

The Xenodermids are restricted to tropical regions in Asia, mostly occupying rainforest. There are 18 species in six genera. Some species have bizarre skins, some with rows of bead-like scales lending them the colloquial name of dragon snakes. Not much is known regarding their life histories. Two species are threatened: *Achalinus jinggangensis* is Critically Endangered and *Achalinus hainanus* is Vulnerable.

2.4.35 Family: Pareidae

Asian slug-eaters are distantly related to true colubrid snakes. They are mostly slender in profile and largely nocturnal in habits, feeding exclusively on snails and slugs. There are approximately 20 species in three genera. Many species are listed as Data Deficient, so their conservation status is not well documented. Being small, nocturnal and specialist feeders, they do not feature in trade (Mattison, 1995).

2.4.36 Family: Viperidae

The Viperidae is one of the most intensely studied snake families and often feature in ecological studies, i.e. *Vipera* in Europe, *Crotalus* in North America and *Bitis* in Africa (Mattison, 1995; Herrmann et al., 1999; Lenk et al., 1999; Greene, 2003). This family has solenoglyphous fang structure whereby the long fangs are hinged and fold to lie parallel to the roof of the mouth. Adders and vipers feature prominently in snakebite and as a result, much has been written regarding venom, morbidity and mortality. Despite being venomous, they are highly sought after in private reptile collections due to their sedentary behaviour and often striking features such as pattern, colour and head ornamentation. Three main clades have been identified – the Azemiopinae of Asia, the Old World Viperinae and New and Old World Crotalinae, containing the pit-vipers. The Azemiopinae has two species in one genus; the Viperinae approximately 101 species in 13 genera and the Crotalinae approximately 247 species in 21 genera (Table S2.1). Recent taxonomic and biogeographical reviews include Lenk et al. (1999) for *Bitis*; Malhotra and Thorpe (2000; 2004) for *Trimeresurus*; Arnold et al. (2009) for *Echis* and Menegon et al. (2014) for *Atheris*.

The conservation status of the Viperidae family was reviewed by Maritz et al. (2016). This study concluded that viperines are disproportionately more threatened than most other snake clades and that the number of threatened taxa is currently underestimated. At least three Crotalines are listed as Critically Endangered: *Bothrops alcatraz* from Alcatrazes Island off Brazil; *Bothrops insularis* from a small 43 ha island off south-eastern Brazil and *Crotalus catalinensis* endemic to Isla Santa Catalina in the Gulf of California. A further five viperines are also classified as Critically Endangered. These include *Bitis albanica* from South Africa, *Montivipera wagneri* of Turkey; *Vipera anatolica* of Turkey, and *Vipera darevskii* of Armenia and Turkey and *Vipera orlovi* from Russia. At least 20 further vipers are listed as Endangered and 18 as Vulnerable (Table S2.1).

2.4.37 Family: Homalopsidae

A diverse family of snakes with at least 28 genera distributed throughout Asia, New Guinea and northern Australia (Mattison, 1995; Shine, 2003). These snakes are semi-aquatic and adapted to swamps, mangroves, estuaries and marshes, usually around coastal regions. Homalopsids have valved nostrils and upward projecting eyes as an adaptation to their aquatic environments. They feed on fish and crustaceans such as crabs, as well as amphibians in freshwater environments. Homalopsine snakes are heavily exploited in some parts of Asia. Surprisingly, few are listed as threatened, but this may be due to insufficient data. *Cerberus microlepis* and *Gyiophis vorisi* are listed as Endangered. *Enhydris longicauda* is classified as Vulnerable.

2.4.38 Family: Lamprophiidae

This family is largely an Afro-Malagasy clade of snakes (Vidal et al., 2008; Kelly et al., 2009; Kelly et al., 2010), although some members of the subfamily Psammophiinae penetrate Asia as far as Burma and Thailand. Recently, a clade from the Philippines was described as a new subfamily, the Cyclocorinae, as part of the Lamprophiidae (Weinell & Brown, 2018). The relationships and affiliation of some species within the Lamprophiidae are tentative, as their phylogenetic placement is still uncertain These include *Buhoma*, *Psammodynastes* and *Hypoptophis*. The family has undergone numerous revisions and many cryptic species have been described (Greenbaum et al., 2015; Trape & Mediannikov, 2016; Broadley et al., 2018). Most threatened taxa in this family are confined to Indian Ocean islands, such as Madagascar and the Seychelles.

The African subfamilies Aparallactinae and Atractaspidinae include semi-fossorial snakes whose conservation status is unknown. Most species are small and secretive and therefore difficult to study. The subfamily Cyclocorinae is restricted to the Philippines and currently includes four genera (Weinell & Brown, 2018). At least one species, *Hologerrhum*

dermali is Endangered. The subfamily Lamprophiinae is almost exclusively confined to the African continent, although the enigmatic *Lamprophis geometricus* is endemic to the Seychelles and listed as Endangered. *Lycophidion nanum* is listed as Vulnerable.

The Prosymninae is a small, exclusively sub-Saharan African subfamily containing 16 species in one genus (Spawls et al., 2018). These small, semi-fossorial snakes feed exclusively on lizard and possibly snake eggs. The brilliantly coloured *Prosymna ornatissima* is Critically Endangered. It has a very limited range in the Uluguru Mountains in Tanzania and threatened by habitat destruction and deforestation.

The Psammophiinae is a distinct clade of slender, diurnally-active snakes. The taxonomy is generally stable barring a few wide-ranging species complexes where taxonomy is confused, for example, the *Psammophis sibilans-phillipsi-mossambicus* species complex. Molecular studies have also transferred several species to different genera, for example, *Dromophis* = *Psammophis* and *Ramphiophis acutus* and *R. togoensis* were transferred to *Psammophylax*. Although some species are exceedingly rare, such as *Psammophis pulcher* from East Africa (Spawls et al., 2018), most species are common and widespread and therefore there are few conservation issues. *Psammophis leightoni* from the Western Cape fynbos biome in South Africa is Vulnerable.

The subfamily Pseudaspidinae currently contains two species: *Pseudaspis cana* and *Pythonodipsas carinata*. There are no conservation issues at present, although the wide-spread *Pseudaspis cana* appears to be declining in disturbed grassland habitats (pers. obs. WRS).

The remaining subfamily Pseudoxyrhophiinae is the most threatened subfamily. Its members are largely confined to Madagascar and surrounding Indian Ocean islands, with a few representatives on the African mainland. *Compsophis vinckei* and *Pseudoxyrhopus anakfinaensis* from Madagascar are Critically Endangered. A further eight Madagascan species are Endangered and ten Vulnerable (Table S2.1). The enigmatic *Montaspis gilvomaculata* from

the KwaZulu-Natal Drakensberg mountains is currently included in this subfamily and only known from less than five specimens. No recent verified sightings are known. Its population status and taxonomy are currently unknown and therefore listed as Data Deficient.

2.4.39 Family Elapidae

The proteroglyphous family Elapidae has three main clades – the Afro-Asian Elapinae; the Australasian Hydrophiinae (which includes the sea snakes and New Guinea-Australian terrestrial elapids); and a clade which includes the American coral snakes *Micrurus* and *Micruroides* and probably the Asian *Sinomicrurus*. (Keogh, 1998; Lawson et al., 2005; Kelly et al., 2009; Lee et al., 2016) Some authors include the sea kraits *Laticauda* in their own subfamily, the Laticaudinae.

Few elapids are listed as threatened despite many species such as cobras being heavily exploited or persecuted. *Micrurus ruatanus* is Critically Endangered and restricted to a small island off the coast of Honduras. At least five terrestrial elapids are listed as Endangered.

The sea snakes (Hydrophiinae; Laticaudinae) are the most threatened group of elapid snakes and many species have experienced alarming declines (Elfes et al., 2013; Lukoscheck et al., 2013). *Aipysurus apraefrontalis* and *A. foliosquama* are Critically Endangered. *Aipysurus fuscus* is Endangered.

2.4.40 Family Colubridae

The Colubridae is the most speciose clade of extant snakes with > than 1 854 species, representing almost 50% of all snakes. The systematics are still in a state of flux. Some authors have elevated the subfamilies to full family status. This study follows the arrangement of Figueroa et al. (2016), who include eight colubrid subfamilies in their cladogram. The placement of some genera within these families is however still uncertain and will change pending further systematic reviews.

The subfamily Sibynophiinae includes 11 species in two genera found in Asia and the Neotropics. There are no known conservation issues.

The subfamily Natricinae is a diverse family distributed across the globe. Many species are affiliated with wetlands, but some have adapted to more xeric environments. *Opisthotropis kikuzatoi* from Japan is Critically Endangered. A further five Asian and North American species are listed as Endangered and five Vulnerable (Table S2.1).

The subfamily Pseudoxenodontinae is another small clade with only ten species in two genera found in Asia. Conservation issues are not documented for these species.

The subfamily Dipsadinae is an incredibly speciose clade found in the Americas. *Thermophis* from high-altitude China has been included within this subfamily but represents a biogeographic enigma. *Erythrolamprus* and *Geophis* each has at least 50 species respectively. The taxonomy and phylogeny have been discussed by various authors (Vidal et al., 2000; Blair Hedges et al., 2009; Grazziotin et al., 2012; Pyron et al., 2016). It is the most threatened subfamily of colubrids, as many species are confined the West Indian and Caribbean Island groups of extremely high conservation concern. Major threats include habitat destruction and the introduction of invasive species, especially mongoose. It includes at least three Extinct species: *Alsophis antiguae*; *Clelia errabunda* and *Erythrolamprus perfuscus* (discussed above). Some species currently listed as Critically Endangered may also in fact be extinct (IUCN database, 2018). At least 15 species are Critically Endangered and a further 27 Endangered and 24 Vulnerable (Table S2.1).

The subfamily Grayinae is sometimes included under the Natricinae. This subfamily contains four well-defined species confined to tropical West and Central Africa. They are large, aquatic, diurnally active snakes frequenting forests. Most species are widely distributed and can be exceedingly common in some places. They are exploited for food and medicinal uses in

many countries where they occur (Pauwels et al., 2002). None are currently listed under any threatened category.

The subfamily Calamariinae is a subfamily of Asian snakes with many species that feed on crustaceans such as crabs. Most species are semi-aquatic and share similar behavioural traits as the Family Homalopsidae (see above). Two species, *Calamaria ingeri* from Peninsular Malaysia and *C. prakkei* from Sabah (Borneo) are listed as Critically Endangered. *Calamaria pfefferi*, *C. yunnanensis* and *Pseudorabdion montanum* are Endangered and *Pseudorabdion mcnamarae* and *P. talonuran* are Vulnerable. This subfamily is heavily exploited as a food resource in Asia, so many more species may be of conservation concern.

The subfamily Ahaetuliinae was recently described by Figueroa et al. (2016) and includes four genera of diurnally active, largely arboreal, slender snakes, which are distributed from northern Australia, across Asia to India. *Ahaetulla perroteti* from India is Endangered. *Dryophiops philippina* from the Philippines is Vulnerable.

The subfamily Colubrinae is yet another speciose clade, but their taxonomy is also not fully resolved. There morphology and behaviour vary considerably between species and numerous sub-clades or tribes have been described, i.e. Boigini; Dispholidini; Coronellini; Philothamnini; etc. Like the Natricines, this subfamily is distributed throughout the New and Old World. At least 12 species are assessed as Critically Endangered, 16 Endangered and 16 Vulnerable (Table S2.1).

2.5 DISCUSSION

Based on the above assessment, we are still far from understanding true global snake species diversity and we can expect the current figure to increase significantly in the foreseeable future. Whilst most of the recently described taxa include small, secretive species or cryptic taxa identified using molecular gene sequencing, some examples are of truly enigmatic species.

These include the large adder *Bitis harenna* from the Pare Mountains in Ethiopia (Wade et al., 2016); the desert-dwelling spider-tailed viper *Pseudocerastes urarachnoides* from Iran which has a spider-like caudal appendage used as a lure to attract the attention of birds (Bostanchi et al., 2006) and the silver boa *Chilabothrus argentum*, a Critically Endangered species from the Conception Island Bank in the Bahamas (Reynolds et al., 2016).

The taxonomy, evolutionary history and phylogenies of extant snakes has increased substantially over the last two to three decades with hundreds of systematic and revisionary studies having been undertaken. These studies have increased our understanding of species diversity and evolutionary histories and contributed to a more stable higher taxonomy. However, there are still noteworthy gaps and different consensus between taxonomists. Further taxon sampling will eventually resolve these issues.

The primary focus of this paper is the conservation of snakes globally. The present study found approximately 2 167 species assessed by the IUCN. This represents 57.8% of extant snake species. In addition, 441 species were found to be 'Data Deficient'. This means that the conservation status of over half of global snakes are not known or poorly understood. Of species assessed, at least 10% are of conservation concern. However, this figure may be underestimated as found in a recent study focusing on the Viperidae (adders and vipers), whereby the authors concluded that nearly half of species that had sufficient data to calculate a Threat Index (TI) were listed as Data Deficient by the IUCN, but which, however, appear to be of conservation concern (Maritz et al., 2016).

Of the 285 snake species listed under the three highest threat categories (Critically Endangered; Endangered and Vulnerable), 119 (41.8%) are confined to oceanic islands. A 153 species are found largely on continental land masses. This represents 53.7% of species under the three highest threatened categories, however, many of these species are range-restricted and habitat specialists, confined to 'land islands' such as isolated mountain ranges or forests. For

example, many threatened African taxa from mainland Africa are habitat specialists with restricted ranges, i.e. *Bitis inornata* is restricted to a few localities in the Sneeuberg and Compassberg in the Eastern Cape of South Africa; *Atheris barbouri* to mid-altitude woodland in the Udzungwa and Ukinga Mountains in Tanzania (Spawls et al., 2018). Overall, there is no evidence to suggest that island endemic snakes are any more threatened than those found on continental landmasses when all threat categories are merged. However, the percentage is higher in the Critically Endangered category and all five Extinct taxa were island endemics. The two island regions of highest conservation priority for snakes is Madagascar and the Caribbean/West Indian island cluster. A study undertaken by Tershy et al. (2015) found that species diversity on islands is disproportionately higher than that compared with continents when assessing plants, birds, rodents and linguistic diversity. The situation corresponding to snake fauna is currently unknown, but based on limited data, the impact appears higher and should be the subject of future studies on snake diversity and conservation.

Habitat specialists, island endemics and range-restricted species may not necessarily be the only snakes of conservation concern. A pool of emerging evidence is accumulating indicating that traditionally common and widespread species may be experiencing alarming population declines (Gibbons et al., 2000; Reading et al., 2010). Snake population declines are often attributable to a range of factors and often interlinked in complex ways. Invasive plants may impact negatively on herbivorous rodents and in turn affect local snake populations through predator-prey dynamics. Climate change, pollution, habitat destruction, afforestation, deforestation, exploitation, persecution, harvesting, fire regimes, grazing impact, road-mortality, urban development and pathogens have all impacted negatively on wide-ranging snake species (Rudolph & Burgdorf, 1997; Winne et al., 2007; Santos & Lorente, 2009; Clark et al., 2011; Godley & Moler, 2013; Lukoscheck et al., 2013). But in exceptional

circumstances, have benefitted others, for example, the building of dams for agriculture may increase amphibian populations and in turn snakes that feed on amphibians.

Evolutionary traits leading to current global snake diversity and biogeographic patterns for extant snake clades have been discussed by Pyron and Burbrink (2011). Their study has hypothesised that the evolution of toxic salivary components and venom has been a primary driver in species diversity in many snake lineages, broadening the breadth of potential prey available to snakes therefore increasing speciation rates. The exceptional diversity and radiation of New World Dipsadines is explained by the colonization of novel habitats and relatively low competition (Pyron & Burbrink, 2011).

Despite gaps in our knowledge regarding taxonomy, species diversity and conservation, the conservation of squamate reptiles, including snakes, has been attracting increased attention (Böhm et al., 2013; Elfes et al., 2013; Maritz et al., 2016; Tolley et al., 2016). Snakes generally lead secretive and sedentary lives making ecological and population studies challenging. A greater understanding of their distribution, biogeography, taxonomy and ecological and lifestyle traits will allow for more robust conservation assessments and the formulation of species management plans. These should never be read in isolation but integrated into greater management strategies for the conservation of key global biodiversity hotspots.

2.6 ACKNOWLEDGEMENTS

We are grateful to the University of KwaZulu-Natal and the National Research Foundation (ZA) for funding CTD.

2.7 REFERENCES

Adalsteinsson, S. A., Branch, W. R., Trape, S., Vitt, L. J. & Blair Hedges, S. 2009. Molecular phylogeny, classification, and biogeography of snakes of the Family Leptotyphlopidae (Reptilia, Squamata). *Zootaxa* 2244: 1-50.

Allender, M. C., Raudabaugh, D. B., Gleason, F. H. & Miller, A. N. 2015. The natural history, ecology, and epidemiology of *Ophidiomyces ophiodiicola* and its potential impact on free-ranging snake populations. *Fungal Ecology* 17: 187-196.

Arnold, E. N., Robinson, M. D. & Carranza, S. 2009. A preliminary analysis of phylogenetic relationships and biogeography of dangerously venomous carpet vipers, *Echis* (Squamata, Serpentes, Viperidae) based on mitochondrial DNA sequences. *Amphibia-Reptilia* 30: 273-282.

Bates, M. F. & Broadley, D. G. 2018. A revision of the egg-eating snakes of the genus *Dasypeltis* (Squamata: Colubridae: Colubrinae) in north-eastern Africa and south-western Arabia, with descriptions of three new species. *Indago* 34: 1-95.

Bawaskar, H. S., Bawaskar, P. H. & Bawaskar, P. H. 2017. Snakebite in India: a neglected disease of poverty. *Lancet* 390: 1947-1948. http://dx.doi.org/10.1016/s0140-6736(17)31656-2

Bostanchi, H., Anderson, S. C., Kami, H. G. & Papenfuss, T. J. 2006. A new species of *Pseudocerastes* with elaborate tail ornamentation from Western Iran (Squamata: Viperidae). *Proceedings of the California Academy of Sciences* 57: 443-450.

Broadley, D. G. 2002. A review of the species of *Psammophis* Boie found south of latitude 12°S (Serpentes: Psammophiinae). *African Journal of Herpetology* 51: 83-119.

Broadley, D. G. & Wüster, W. 2004. A review of the southern African 'non-spitting' cobras (Serpentes: Elapidae: *Naja*). *African Journal of Herpetology* 53: 101-122.

Broadley, D. G., Tolley, K. A., Conradie, W., Wishart, S., Trape, J-F., Burger, M., Kusamba, C., Zassi-Boulou, A-G. & Greenbaum, E. 2018. A phylogeny and genus-level revision of the African file snakes *Gonionotophis* Boulenger (Squamata: Lamprophiidae). *African Journal of Herpetology* 67: 43-60. https://doi.org/10.1080/21564574.18.1423578

Brooks, S. E., Allison, E. H., Gill, J. A. & Reynolds, J. D. 2010. Snake prices and crocodile appetites: aquatic wildlife supply and demand on Tonle Sap Lake, Cambodia. *Biological Conservation* 143: 2127-2135. Doi:10.1016/j.biocon.2010.05.023

Burbrink, F. T., Lawson, R. & Slowinski, J. B. 2000. Mitochondrial DNA phylogeography of the polytypic North American rat snake (*Elaphe obsoleta*): a critique of the subspecies concept. *Evolution* 54: 2107-2118. https://doi.org/10.1554/0014-3820(2000)054[2107:MDPOTP]2.0.CO;2

Ceriaco, L. M. P., Marques, M. P., Schmitz, A. & Bauer, A. M. 2017. The "Cobra-preta" of Sǎo Tomé Island, Gulf of Guinea, is a new species of *Naja* Laurenti, 1768 (Squamata: Elapidae). *Zootaxa* 4324: 121-141. https://doi.org/10.11646/zootaxa.4324.1

Chen, X., Lemmon, A. R., Lemmon, E. M., Pyron, R. A. & Burbrink, F. T. 2017. Using phylogenomics to understand the link between biogeographic origins and regional diversification in ratsnakes. *Molecular Phylogenetics and Evolution* 111: 206-218. http://dx.doi.org/10.1016/j.ympev.2017.03.017

Chippaux, J-P. 2017. Snakebite envonomation turns again into a neglected tropical disease! *Journal of Venomous Animals and Toxins including Tropical Diseases* 23: 38. doi 10.1186/s40409-017-0127-6

Elfes, C. T., et al. 2013. Fascinating and forgotten: the conservation status of marine elapid snakes. *Herpetological Conservation and Biology* 8: 37-52.

Figueroa, A., McKelvy, A. D., Lee Grismer, L., Bell, C. D. & Lailvaux, P. 2016. A species level phylogeny of extant snakes with the description of a new colubrid subfamily and genus. *PLoS One* 11: e0161070. https://doi:10.1371/journal.pone06171070

Franklinos, L. H. V., Lorch, J. M., Bohuski, E., Fernandez, J. R-R., Wright, O. N., Fitzpatrick, L., Petrovan, S., Durrant, C., Linton, C., Balaz, V., Cunningham, A. A. & Lawson, B.

2017. Emerging fungal pathogen *Ophidiomyces ophiodiicola* in wild European snakes. *Scientific Reports* 7: 3844. doi:10.1038/s41598-017-03352-1

Fry, B. G. 2018. Snakebite: when the human touch becomes a bad touch. *Toxins* 10: 170. doi:10.3390/toxins10040170.

Gibbons. J. W. et al. 2000. The global decline of reptiles, déjà vu amphibians. *BioScience* 50: 653-666.

Grazziotin, F. G., Zaher, H., Murphy, R. W., Scrocchi, G., Benavides, M. A., Zhang, Y-P & Bonatto, S. L. 2012. Molecular phylogeny of the New World Dipsadidae (Serpentes: Colubroidea): a reappraisal. *Cladistics* 1: 1-23.

Greenbaum, E., Portillo, F., Jackson, K. & Kusamba, C. 2015. A phylogeny of Central African *Boaedon* (Serpentes: Lamprophiidae), with the description of a new cryptic species from the Albertine Rift. *African Journal of Herpetology* 64: 18-38. http://dx.doi.org/10.1080/21564574.2014.996189

Hawlitschek, O., Nagy, Z. T. & Glaw, F. 2012. Island evolution and systematic revision of Comoran snakes: why and when subspecies still make sense. *PLoS ONE* 7: e42970. Doi:10.1371/journal.pone.0042970

Hedges, S., Couloux, A. & Vidal, N. 2009. Molecular phylogeny, classification and biogeography of West Indian racer snakes of the Tribe Alsophiini (Squamata, Dipsadidae, Xenodontinae). *Zootaxa* 2067: 1-28.

Hedges, S., Marion, A. B., Lipp, K. M., Marin, J. & Vidal, N. 2014. A taxonomic framework for typhlopid snakes from the Caribbean and other regions (Reptilia, Squamata). *Caribbean Herpetology* 49: 1-61.

IUCN Red List of Threatened Species 2018-1. www.iucnredlist.org Accessed August 2018.

Kaiser, H., Crother, B. I., Kelly, C. M. R., Luiselli, L., O'Shea, M., Ota, H. et al. 2013. Best practices: in the 21st Century, taxonomic decisions in herpetology are acceptable only when supported by a body of evidence and published via peer-review. *Herpetological Review* 44: 8-23.

Kelly, C. M. R., Barker, N. P., Vilett, M. H. & Broadley, D.G. 2009. Phylogeny, biogeography and classification of the snake superfamily Elapoidea: a rapid radiation in the late Eocene. *Cladistics* 25: 38-63.

Kelly, C. M. R., Branch, W. R., Broadley, D. G., Barker, N. P. & Villet, M. H. 2010. Molecular systematics of the African snake family Lamprophiidae Fitzinger, 1843 (Serpentes: Elapoidea), with a particular focus on the genera *Lamprophis* Fitzinger, 1843 and *Mehelya* Csiki, 1903. *Molecular Phylogenetics and Evolution* 58: 415-426.

Keogh, J. S. 1998. Molecular phylogeny of elapid snakes and a consideration of their biogeographic history. *Biological Journal of the Linnaean Society* 63: 177-203.

Lawson, R., Slowinski, J. B., Crother, B. I. & Burbrink, F. T. 2005. Phylogeny of the Colubroidea (Serpentes): New evidence from mitochondrial and nuclear genes. *Molecular Phylogenetics and Evolution* 37: 581-601.

Lee, M. S. Y., Sanders, K. L., King, B. & Palci, A. 2016. Diversification rates and phenotypic evolution in venomous snakes (Elapidae). *Royal Society Open Science* 3: 150277. http://dx.doi.org/10.1098/rsos.150277

Lenk, P., Herrmann, H-W., Joger, U. & Wink, M. 1999. Phylogeny and taxonomic subdivision of *Bitis* (Reptilia: Viperidae) based on molecular evidence. *Kaupia* 8: 31-38.

Leviton, A. E., Siler, C. D., Weinell, J. L. & Brown, R. M. 2018. Synopsis of the Snakes of the Philippines – A synthesis of data from biodiversity repositories, field studies and literature. *Proceedings of the California Academy of Sciences* Series 4, 64: 399-568.

Lukoschek, V., Beger, M., Ceccarelli, D., Richards, Z. & Pratchett, M. 2013. Enigmatic declines of Australia's sea snakes from a biodiversity hotspot. *Biological Conservation* 166: 191-202. http://dx.doi.org/10.1016/j.biocon.2013.07.004

Malhotra, A. & Thorpe, R. S. 2000. A phylogeny of the *Trimeresurus* group of pit vipers: new evidence from a mitochondrial gene tree. *Molecular Phylogenetics and Evolution* 16: 199-211.

Malhotra, A. & Thorpe, R. S. 2004. A phylogeny of four mitochondrial gene regions suggests a revised taxonomy for Asian pitivipers (*Trimeresurus* and *Ovophis*). *Molecular Phylogenetics and Evolution* 32: 83-100.

Maritz, B., Penner, J., Martins, M., Crnobrnja-Isailović, Spear, S., Alencar, L. R. V., Sigala-Rodriguez, J., Messenger, K., Clark, R. W., Soorae, P., Luiselli, L., Jenkins, C. & Greene, H. W. 2016. Identifying global priorities for the conservation of vipers. *Biological Conservation* 204: 94-102.

Means, D. B. 2009. Effects of rattlesnake roundups on the Eastern Diamondback Rattlesnake (*Crotalus adamanteus*). *Herpetological Conservation and Biology* 4: 132-141.

Menegon, M., Loader, S. P., Marsden, S. J., Branch, W. R., Davenport, T. R. B. & Ursenbacher, S. 2014. The genus *Atheris* (Serpentes: Viperidae) in East Africa: Phylogeny and the role of rifting and climate in shaping the current pattern of species diversity. *Molecular Phylogenetics and Evolution* 79: 12-22. http://dx.doi.org/10.1016/j.ympev.2014.06.007

Miralles, A., Marin, J., Markus, D. Herrel, A., Hedges, S. B. & Vidal, N. 2018. Molecular evidence for the paraphyly of Scolecophidia and its evolutionay implications. *Journal of Evolutionary Biology* 31 (12).

Pincheira-Donoso, D., Bauer, A.M., Meiri, S. & Uetz, P. 2013. Global taxonomic diversity of living reptiles PloS ONE 8 (3): e59741. Doi: 10.1371/journal.pone.0059741

Pyron, R. A. & Burbrink, F. T. 2011. Extinction, ecological opportunity, and the origins of global snake diversity. *Evolution* doi:10.1111/j.1558-5646.2011.01437

Pyron, R. A., Burbrink, F. T. & Wiens, J. J. 2013. A phylogeny and revised classification of Squamata, including 4161 species of lizards and snakes. *BMC Evolutionary Biology* 13: 93 http://www.biomedcentral.com/1471-2148/13/93

Pyron, R. A. & Wallach, V. 2014. Systematics of the blind snakes (Serpentes: Scolecophidia: Typhlopoidea) based on molecular and morphological evidence. *Zootaxa* 3829: 001-081.

Pyron, R. A., Reynolds, R. G. & Burbrink, F. T. 2014. A taxonomic revision of boas (Serpentes: Boidae). *Zootaxa* 3846: 249-260. http://dx.doi.org/10.11646/zootaxa.3846.2.5

Pyron, R. A., Arteaga, A., Echevarria, L. Y. & Torres-Caravajal, O. 2016. A revision and key for the tribe Diaphorolepidini (Serpentes: Dipsadidae) and checklist for the genus *Synophis*. *Zootaxa* 4171: 293-320. http://doi.org/10.11646/zootaxa.4171.2.4

Reading, C. J., Luiselli, L.M., Akani, G. C., Bonnet, X., Mari, G., Ballouard, J. M., Filippi, E., Naulleau, G., Pearson, D. & Rugiero, L. 2010. Are snake populations in widespread decline? *Biology Letters* 6: 777-780 doi:10.1098/rsbl.2010.0373

Reynolds, R. G., Puento-Rolón, A. R., Aviles-Rodriguez, K. J., Geneva, A. J. & Herrmann. 2016. Discovery of a remarkable new boa from the Conception Islands, Bahamas. *Breviora* 549: 1-19.

Saleh, M. & Sarhan. M. 2016. The egg-eating snake (Colubridae: *Dasypeltis*) of Faiyum, Egypt, with the description of a new species. *Bulletin Society Herpetology France.* 160: 25-48.

Schmidt, K. P. & Inger, R. F. 1957. Living Reptiles of the World. Hamish Hamilton, London. 287pp.

Segniagbeto, G. H., Petrozzi, F., Aïdam, A. & Luiselli, L. 2013. Reptiles traded in the fetish market of Lomé, Togo (West Africa). *Herpetological Conservation and Biology* 8: 400-408.

Shine, R. 1988. Australian Snakes – A natural history. Reed New Holland. 224pp.

Spawls, S., Howell, K., Hinkel, H. & Menegon, M. 2018. Field Guide to East Africa Reptiles. Second Edition. Bloomsbury. 624pp.

Streicher, J. W. & Wiens, J. J. 2016. Phylogenetic analyses reveal novel relationships among snake families. *Molecular Phylogenetics and Evolution* 100: 160-169. http://dx.doi.org/10.1016/j.ympev.2016.04.015

Tershy, B. R., Shen, K-W., Newton, K. M., Holmes, N. D. & Croll, D. A. 2015. The importance of islands for the protection of biological and linguistic diversity. *BioScience* 65: 592-597. https://doi.org/10.1093/biosci/biv031

Thomson, S. A., Pyle, R. L., Ahyong, S. T., Alonso-Zarazaga, M., Ammirati, J., Araya, J. F. et al. 2018. Taxonomy based on science is necessary for global conservation. *PLoS Biology* 16: e2005075. https://doi.org/10.1371/journal.pbio.2005075

Tolley, K. A., Alexander, G. J., Branch, W. R., Bowles, P. & Maritz, B. 2016. Conservation status and threats for African reptiles. *Biological Conservation* 204: 63-71.

Trape, J-F., Chirio, L., Broadley, D. G. & Wüster, W. 2009. Phylogeography and systematic revision of the Egyptian cobra (Serpentes: Elapidae: *Naja haje*) species complex, with the description of a new species from West Africa. *Zootaxa* 2236: 1-25.

Trape, J-F. & Mané, Y. 2006. Le genre *Dasypeltis* Wagler (Serpentes: Colubridae) en Afrique de l'Ouest: description de trois espéces et d'une sous-espéce nouvelles. *Bulletin de la Société Herpétologique de France* 119: 27-56.

Trape, J-F. & Mediannikov, O. 2016. Cinq serpents nouveaux du genre *Boaedon* Duméril, Bibron & Duméril, 1854 (Serpentes: Lamprophiidae) en Afrique centrale. *Bulletin de la Société Herpétologique de France* 159: 58-107.

Uetz, P., Freed, P. & Hošek, J. (eds) 2018. The Reptile Database http://www.reptile-database.org

Vidal, N., Kindl, S. G., Wong, A. & Blair Hedges. 2000. Phylogenetic relationships of Xenodontine snakes inferred from 12S and 16S ribosomal RNA sequences. *Molecular Phylogenetics and Evolution* 14: 389-402. Doi:10.1006/mpev.1999.0717

Vidal, N., Branch, W. R., Pauwels, O. S. G., Blair Hedges, S., Broadley, D. G., Wink, M., Cruaud, C., Joger, U. & Nagy, Z. T. 2008. Dissecting the major African snake radiation: a molecular phylogeny of the Lamprophiidae Fitzinger (Serpentes, Caenophidia). *Zootaxa* 1945: 51-66.

Wallach, V., Mercurio, V. & Andreone, F. 2007. Rediscovery of the enigmatic blind snake genus *Xenotyphlops* in northern Madagascar, with description of a new species (Serpentes: Typhlopidae). *Zootaxa* 1402: 59-68.

Wallach, V., Williams, K. L. & Boundy, J. 2014. Snakes of the World – A catalogue of living and extinct species. CRC Press.

Weinell, J. L. & Brown, R. M. 2018. Discovery of an old, archipelago-wide, endemic radiation of Philippine snakes. *Molecular Phylogenetics and Evolution* 119: 144-150. https://doi.org/10.1016/j.ympev.2017.11.004

Wilcox, T. P., Zwickl, D. J. Heath, T. A. & Hillis, D. M. 2002. Phylogenetic relationships of the dwarf boas and a comparison of Bayesian and bootstrap measures of phylogenetic support. *Molecular Phylogenetics and Evolution* 25: 361-371.

Wüster, W., Chirio, L., Trape, J-F., Ineich, I., Jackson, K., Greenbaum, E., Barron, C., Kusamba, C., Nagy, Z. T., Storey, R., Hall, C., Wüster, C. E., Barlow, A. & Broadley, D. G. 2018. Integration of nuclear and mitochondrial gene sequences and morphology reveals unexpected diversity in the forest cobra (*Naja melanoleuca*) species complex in Central and West Africa (Serpentes: Elapidae). *Zootaxa* 4455: 068-098. https://doi.org/10.11646/zootaxa.4455.1.3

Zhou, Z. & Jiang, Z. 2004. International trade status and crisis for snake species in China. *Conservation Biology* 18: 1386-1394.

Supplementary Table S2.1: Snakes listed in the categories (Extinct, Critically Endangered, Endangered and Vulnerable) on the IUCN database, showing their biogeographic affinity (continental landmass or oceanic island).

Species:	Family:	IUCN Category:	Biogeographical Affinity:
EXTINCT			
Typhlops cariei	Typhlopidae	Extinct	Island
Bolyeria multocarinata	Bolyeriidae	Extinct	Island
Alsophis antiguae	Colubridae; Dipsadinae	Extinct	Island
Clelia errabunda	Colubridae; Dipsadinae	Extinct	Island
Erythrolamprus perfuscus	Colubridae; Dipsadinae	Extinct	Island
CRITICALLY ENDANGERED			
Mitophis asbolepis	Leptotyphlopidae; Epictinae	Critically Endangered	Island
Mitophis calypso	Leptotyphlopidae; Epictinae	Critically Endangered	Island
Mitophis leptepileptis	Leptotyphlopidae; Epictinae	Critically Endangered	Island
Tetracheilostoma carlae	Leptotyphlopidae; Epictinae	Critically Endangered	Island
Anilios insperatus	Typhlopidae; Asiatyphlopinae	Critically Endangered	Continent
Typhlops agoralionis	Typhlopidae; Typhlopinae	Critically Endangered	Island
Typhlops epactius	Typhlopidae; Typhlopinae	Critically Endangered	Island
Typhlops lazelli	Typhlopidae; Typhlopinae	Critically Endangered	Island
Xenotyphlops grandidieri	Xenotyphlopidae	Critically Endangered	Island
Tropidophis hendersoni	Tropidophiidae	Critically Endangered	Island
Chilabothrus argentum	Boidae	Critically Endangered	Island
Achalinus jinggangensis	Xenodermidae	Critically Endangered	Continent
Bothrops alcatraz	Viperidae; Crotalinae	Critically Endangered	Island
Bothrops insularis	Viperidae; Crotalinae	Critically Endangered	Island
Crotalus catalinensis	Viperidae; Crotalinae	Critically Endangered	Island
Bitis albanica	Viperidae; Viperinae	Critically Endangered	Continent
Montivipera wagneri	Viperidae; Viperinae	Critically Endangered	Continent

Vipera anatolica	Viperidae; Viperinae	Critically Endangered	Continent
Vipera darevskii	Viperidae; Viperinae	Critically Endangered	Continent
Vipera orlovi	Viperidae; Viperinae	Critically Endangered	Continent
Micrurus ruatanus	Elapidae; Elapinae	Critically Endangered	Island
Aipysurus apraefrontalis	Elapidae; Hydrophiinae	Critically Endangered	Ocean
Aipysurus foliosquama	Elapidae; Hydrophiinae	Critically Endangered	Ocean
Prosymna ornatissima	Lamprophiidae; Prosymninae	Critically Endangered	Continent
Compsophis vinckei	Lamprophiidae; Pseudoxyrhophiinae	Critically Endangered	Island
Pseudoxyrhopus ankafinaensis	Lamprophiidae; Pseudoxyrhophiinae	Critically Endangered	Island
Calamaria ingeri	Colubridae; Calamariinae	Critically Endangered	Dual
Calamaria prakkei	Colubridae; Calamariinae	Critically Endangered	Island
Chironius vincenti	Colubridae; Colubrinae	Critically Endangered	Island
Dendrophidion boschelli	Colubridae	Critically Endangered	Continent
Drymoluber apurimacensis	Colubridae; Colubrinae	Critically Endangered	Continent
Gongylosoma mukutense	Colubridae; Colubrinae	Critically Endangered	Island
Lampropeltis herrerae	Colubridae; Colubrinae	Critically Endangered	Island
Lycodon chrysoprateros	Colubridae; Colubrinae	Critically Endangered	Island
Masticophis anthonyi	Colubridae; Colubrinae	Critically Endangered	Continent
Oligodon booliati	Colubridae; Colubrinae	Critically Endangered	Island
Opisthotropis kikuzatoi	Colubridae	Critically Endangered	Island
Tantilla insulamontana	Colubridae; Colubrinae	Critically Endangered	Continent
Tantilla petersi	Colubridae; Colubrinae	Critically Endangered	Continent
Tantilla tritaeniata	Colubridae; Colubrinae	Critically Endangered	Island
Alsophis antillensis	Colubridae; Dipsadinae	Critically Endangered	Island

Borikenophis sanctaecrucis	Colubridae; Dipsadinae	Critically Endangered	Island
Emmochliophis miops	Colubridae	Critically Endangered	Continent
Enulius bifoveatus	Colubridae; Dipsadinae	Critically Endangered	Island
Erythrolamprus cursor	Colubridae; Dipsadinae	Critically Endangered	Island
Erythrolamprus ornatus	Colubridae; Dipsadinae	Critically Endangered	Island
Geophis damiani	Colubridae; Dipsadinae	Critically Endangered	Continent
Hypsirhynchus ater	Colubridae; Dipsadinae	Critically Endangered	Island
Hypsirhynchus melanichnus	Colubridae; Dipsadinae	Critically Endangered	Island
Ialtris parishi	Colubridae; Dipsadinae	Critically Endangered	Island
Omoadiphas cannula	Colubridae; Dipsadinae	Critically Endangered	Continent
Omoadiphas texiquatensis	Colubridae; Dipsadinae	Critically Endangered	Continent
Rhadinella tolpanorum	Colubridae; Dipsadinae	Critically Endangered	Continent
Sibon merendonensis	Colubridae; Dipsadinae	Critically Endangered	Continent
Synophis plectrovertebralis	Colubridae; Dipsadinae	Critically Endangered	Continent
Trimetopon viguezi	Colubridae; Dipsadinae	Critically Endangered	Continent
Opisthotropis kikuzatoi	Colubridae; Natricinae	Critically Endangered	Island
ENDANGERED			
Mitophis pyrites	Leptotyphlopidae; Epictinae	Endangered	Island
Tetracheilostoma breuili	Leptotyphlopidae; Epictinae	Endangered	Island
Afrotyphlops gierrai	Typhlopidae; Afrotyphlopinae	Endangered	Continent
Letheobia uluguruensis	Typhlopidae; Afrotyphlopinae	Endangered	Continent
Amerotyphlops tasymicris	Typhlopidae; Typhlopinae	Endangered	Island
Amerotyphlops trinitatus	Typhlopidae; Typhlopinae	Endangered	Island
Antillotyphlops monensis	Typhlopidae; Typhlopinae	Endangered	Island
Indotyphlops schmutzi	Typhlopidae; Asiatyphlopinae	Endangered	Island

Rhamphotyphlops exoceoti	Typhlopidae; Asiatyphlopinae	Endangered	Island
Rhamphotyphlops suluensis	Typhlopidae; Asiatyphlopinae	Endangered	Island
Typhlops capitulatus	Typhlopidae; Typhlopinae	Endangered	Island
Typhlops caymanensis	Typhlopidae; Typhlopinae	Endangered	Island
Typhlops gonavensis	Typhlopidae; Typhlopinae	Endangered	Island
Typhlops sylleptor	Typhlopidae; Typhlopinae	Endangered	Island
Typhlops syntherus	Typhlopidae; Typhlopinae	Endangered	Island
Typhlops granti (=Antillotyphlops)	Typhlopidae; Typhlopinae	Endangered	Island
Typhlops tetrathyreus	Typhlopidae; Typhlopinae	Endangered	Island
Typhlops titanops	Typhlopidae; Typhlopinae	Endangered	Island
Platyplectrurus madurensis	Uropeltidae	Endangered	Continent
Rhinophis travancoricus	Uropeltidae	Endangered	Continent
Chilabothrus granti	Boidae	Endangered	Island
Chilabothrus monensis	Boidae	Endangered	Island
Corallus blombergi	Boidae	Endangered	Continent
Corallus cropanii	Boidae	Endangered	Continent
Aspidites ramsayi	Pythonidae	Endangered	Continent
Casarea dussumieri	Bolyeriidae	Endangered	Island
Atropoides indomitus	Viperidae; Crotalinae	Endangered	Continent
Bothriechis marchi	Viperidae; Crotalinae	Endangered	Continent
Bothrops lojanus	Viperidae; Crotalinae	Endangered	Continent
Crotalus pusillus	Viperidae; Crotalinae	Endangered	Continent
Mixcoatlus barbouri	Viperidae; Crotalinae	Endangered	Continent
Mixcoatlus melanurus	Viperidae; Crotalinae	Endangered	Continent
Protobothrops mangshanensis	Viperidae; Crotalinae	Endangered	Continent
Protobothrops sieversorum	Viperidae; Crotalinae	Endangered	Continent
Protobothrops trungkhanhensis	Viperidae; Crotalinae	Endangered	Continent
Trimeresurus buniana	Viperidae; Crotalinae	Endangered	Island
Trimeresurus kanburiensis	Viperidae; Crotalinae	Endangered	Continent
Bitis inornata	Viperidae; Viperinae	Endangered	Continent
Macrovipera schweizeri	Viperidae; Viperinae	Endangered	Island
Montivipera albizona	Viperidae; Viperinae	Endangered	Continent

Montivipera bornmuelleri	Viperidae; Viperinae	Endangered	Continent
Montivipera latifii	Viperidae; Viperinae	Endangered	Continent
Vipera graeca	Viperidae; Viperinae	Endangered	Dual
Vipera kaznakovi	Viperidae; Viperinae	Endangered	Continent
Vipera magnifica	Viperidae; Viperinae	Endangered	Continent
Vipera pontica	Viperidae; Viperinae	Endangered	Continent
Cerberus microlepis	Homalopsidae	Endangered	Island
Gyiophis vorisi	Homalopsidae	Endangered	Continent
Elapsoidea chelazziorum	Elapidae; Elapinae	Endangered	Continent
Elapsoidea nigra	Elapidae; Elapinae	Endangered	Continent
Hemiaspis damelii	Elapidae; Hydrophiinae	Endangered	Continent
Ogmodon vitianus	Elapidae; Hydrophiinae	Endangered	Island
Micrurus catamayensis	Elapidae; Elapinae	Endangered	Continent
Aipysurus fuscus	Elapidae; Hydrophiinae	Endangered	Ocean
Lamprophis geometricus	Lamprophiidae; Lamprophiinae	Endangered	Island
Alluaudina mocquardi	Lamprophiidae; Pseudoxyrhophiinae	Endangered	Island
Heteroliodon fohy	Lamprophiidae; Pseudoxyrhophiinae	Endangered	Island
Liophidium mayottensis	Lamprophiidae; Pseudoxyrhophiinae	Endangered	Island
Lycodryas guentheri	Lamprophiidae; Pseudoxyrhophiinae	Endangered	Island
Lycodryas inopinae	Lamprophiidae; Pseudoxyrhophiinae	Endangered	Island
Phisalixella variabilis	Lamprophiidae; Pseudoxyrhophiinae	Endangered	Island
Pseudoxyrhopus kely	Lamprophiidae; Pseudoxyrhophiinae	Endangered	Island
Thamnosophis martae	Lamprophiidae; Pseudoxyrhophiinae	Endangered	Island
Hologerrhum dermali	Lamprophiidae; Cyclocorinae	Endangered	Island
Ahaetulla perroteti	Colubridae	Endangered	Continent
Calamaria pfefferi	Colubridae; Calamariinae	Endangered	Island
Calamaria yunnanensis	Colubridae; Calamariinae	Endangered	Continent
Pseudorabdion montanum	Colubridae; Calamariinae	Endangered	Island
Boiga bourreti	Colubridae; Colubrinae	Endangered	Continent
Boiga saengsomi	Colubridae; Colubrinae	Endangered	Continent
Chapinophis xanthocheilus	Colubridae; Colubrinae	Endangered	Continent
Euprepiophis perlacea	Colubridae; Colubrinae	Endangered	Continent
Ficimia hardyi	Colubridae; Colubrinae	Endangered	Continent

Lycognathophis seychellensis	Colubridae; Colubrinae	Endangered	Island
Oligodon meyerinkii	Colubridae; Colubrinae	Endangered	Island
Oxybelis wilsoni	Colubridae; Colubrinae	Endangered	Island
Pituophis ruthveni	Colubridae; Colubrinae	Endangered	Continent
Pseudorabdion montanum	Colubridae	Endangered	Island
Tantilla flavilineata	Colubridae; Colubrinae	Endangered	Continent
Tantilla lempira	Colubridae; Colubrinae	Endangered	Continent
Tantilla oolitica	Colubridae; Colubrinae	Endangered	Continent
Tantilla shawi	Colubridae; Colubrinae	Endangered	Continent
Telescopus hoogstraali	Colubridae; Colubrinae	Endangered	Continent
Thermophis zhaoermii	Colubridae; 'Dipsadinae'	Endangered	Continent
Thrasops schmidti	Colubridae; Colubrinae	Endangered	Continent
Adelphicos daryi	Colubridae; Dipsadinae	Endangered	Continent
Adelphicos ibarrorum	Colubridae; Dipsadinae	Endangered	Continent
Alsophis danforthi	Colubridae; Dipsadinae	Endangered	Island
Alsophis rijgersmaei	Colubridae; Dipsadinae	Endangered	Island
Alsophis sanctonum	Colubridae; Dipsadinae	Endangered	Island
Arrhyton tanyplectum	Colubridae; Dipsadinae	Endangered	Island
Atractus carrioni	Colubridae; Dipsadinae	Endangered	Continent
Atractus duboisi	Colubridae; Dipsadinae	Endangered	Continent
Atractus occidentalis	Colubrinae; Dipsadinae	Endangered	Continent
Calamodontophis ronaldoi	Colubridae; Dipsadinae	Endangered	Continent
Chersodromus rubriventris	Colubridae; Dipsadinae	Endangered	Continent
Enulius roatenensis	Colubridae; Dipsadinae	Endangered	Island
Erythrolamprus triscalis	Colubridae; Dipsadinae	Endangered	Island
Erythrolamprus williamsi	Colubridae; Dipsadinae	Endangered	Continent
Geophis fulvoguttatus	Colubridae; Dipsadinae	Endangered	Continent
Geophis talamancae	Colubridae; Dipsadinae	Endangered	Continent
Hypsirhynchus polylepis	Colubridae; Dipsadinae	Endangered	Island
Ialtris agyrtes	Colubridae; Dipsadinae	Endangered	Island
Rhadinaea marcellae	Colubridae; Dipsadinae	Endangered	Continent
Rhadinaea montana	Colubridae; Dipsadinae	Endangered	Continent
Rhadinaea stadelmani	Colubridae; Dipsadinae	Endangered	Continent
Rhadinella hempsteadae	Colubridae; Dipsadinae	Endangered	Continent
Rhadinella posadasi	Colubridae; Dipsadinae	Endangered	Continent
Saphenophis sneiderni	Colubridae	Endangered	Continent
Sibon lamari	Colubridae; Dipsadinae	Endangered	Continent
Trimetopon simile	Colubridae; Dipsadinae	Endangered	Continent
Hebius concelarum	Colubridae; Natricinae	Endangered	Island
Hebius metusium	Colubridae; Natricinae	Endangered	Continent
Hologerrhum dermali	Colubridae; Natricinae	Endangered	Island

Opisthotropis alcalai	Colubridae; Natricinae	Endangered	Island
Thamnophis melanogaster	Colubridae; Natricinae	Endangered	Continent
Thamnophis mendax	Colubridae; Natricinae	Endangered	Continent
VULNERABLE			
Amerotyphlops stadelmani	Typhlopidae; Typhlopinae	Vulnerable	Continent
Amerotyphlops tycherus	Typhlopidae; Typhlopinae	Vulnerable	Continent
Antillotyphlops naugus	Typhlopidae; Typhlopinae	Vulnerable	Island
Typhlops hectus	Typhlopidae; Typhlopinae	Vulnerable	Island
Typhlops eperopeus	Typhlopidae; Typhlopinae	Vulnerable	Island
Melanophidium bilineatum	Uropeltidae	Vulnerable	Continent
Uropeltis phipsonii	Uropeltidae	Vulnerable	Continent
Chilabothrus exsul	Boidae	Vulnerable	Island
Chilabothrus subflavus	Boidae	Vulnerable	Island
Python bivittatus bivittatus	Pythonidae	Vulnerable	Continent/Island
Python kyaiktiyo	Pythonidae	Vulnerable	Continent
Simalia oenpelliensis	Pythonidae	Vulnerable	Continent
Achalinus hainanus	Xenodermidae	Vulnerable	Continent
Bothriechis aurifer	Viperidae; Crotalinae	Vulnerable	Continent
Bothriechis rowleyi	Viperidae; Crotalinae	Vulnerable	Continent
Bothrops pirajai	Viperidae; Crotalinae	Vulnerable	Continent
Crotalus stejnegeri	Viperidae; Crotalinae	Vulnerable	Continent
Gloydius shedaoensis	Viperidae; Crotalinae	Vulnerable	Island
Ophryacus undulatus	Viperidae; Crotalinae	Vulnerable	Continent
Trimeresurus honsonensis	Viperidae; Crotalinae	Vulnerable	Island
Trimeresurus nebularis	Viperidae; Crotalinae	Vulnerable	Continent
Atheris barbouri	Viperidae; Viperinae	Vulnerable	Continent
Atheris broadleyi	Viperidae; Viperinae	Vulnerable	Continent
Atheris ceratophora	Viperidae; Viperinae	Vulnerable	Continent
Bitis armata	Viperidae; Viperinae	Vulnerable	Continent
Bitis inornata	Viperidae; Viperinae	Vulnerable	Continent
Bitis schneideri	Viperidae; Viperinae	Vulnerable	Continent
Vipera dinniki	Viperidae; Viperinae	Vulnerable	Continent
Vipera eriwanensis	Viperidae; Viperinae	Vulnerable	Continent
Vipera latastei	Viperidae; Viperinae	Vulnerable	Continent
Vipera ursinii	Viperidae; Viperinae	Vulnerable	Continent
Bungarus andamanensis	Elapidae; Elapinae	Vulnerable	Island
Bungarus slowinskii	Elapidae; Elapinae	Vulnerable	Continent
Micrurus ephippifer	Elapidae; Elapinae	Vulnerable	Continent
Naja atra	Elapidae; Elapinae	Vulnerable	Continent/Island

Naja mandalayensis	Elapidae; Elapinae	Vulnerable	Continent/Island
Naja siamensis	Elapidae; Elapinae	Vulnerable	Continent/Island
Ophiophagus hannah	Elapidae; Elapinae	Vulnerable	Continent/Island
Acanthophis cryptomydros	Elapidae; Hydrophiinae	Vulnerable	Continent
Acanthophis hawkei	Elapidae; Hydrophiinae	Vulnerable	Continent
Austrelaps labialis	Elapidae; Hydrophiinae	Vulnerable	Continent
Denisonia maculata	Elapidae; Hydrophiinae	Vulnerable	Continent
Hoplocephalus bungaroides	Elapidae; Hydrophiinae	Vulnerable	Continent
Loveridgelaps elapoides	Elapidae; Hydrophiinae	Vulnerable	Island
Toxicocalamus longissimus	Elapidae; Hydrophiinae	Vulnerable	Island
Hydrophis semperi	Elapidae; Hydrophiinae	Vulnerable	Ocean
Laticauda crockeri	Elapidae; Laticaudinae	Vulnerable	Ocean
Laticauda schistorhynchus	Elapidae; Laticaudinae	Vulnerable	Ocean
Loveridgelaps elapoides	Elapidae; Hydrophiinae	Vulnerable	Island
Enhydris longicauda	Homalopsidae	Vulnerable	Continent
Buhoma procterae	Lamprophiidae; ‘incertae sedis’	Vulnerable	Continent
Lycophidion nanum	Lamprophiidae; Lamprophiinae	Vulnerable	Continent
Psammophis leightoni	Lamprophiidae; Psammophiinae	Vulnerable	Continent
Brygophis coulangesi	Lamprophiidae; Pseudoxyrhophiinae	Vulnerable	Island
Compsophis zeny	Lamprophiidae; Pseudoxyrhophiinae	Vulnerable	Island
Liophidium therezieni	Lamprophiidae; Pseudoxyrhophiinae	Vulnerable	Island
Liopholidophis grandidieri	Lamprophiidae; Pseudoxyrhophiinae	Vulnerable	Island
Lycodryas citrinus	Lamprophiidae; Pseudoxyrhophiinae	Vulnerable	Island
Lycodryas inornatus	Lamprophiidae; Pseudoxyrhophiinae	Vulnerable	Island
Pararhadinaea melanogaster	Lamprophiidae; Pseudoxyrhophiinae	Vulnerable	Island
Pseudoxyrhopus oblectator	Lamprophiidae; Pseudoxyrhophiinae	Vulnerable	Island
Pseudoxyrhopus sokosoko	Lamprophiidae; Pseudoxyrhophiinae	Vulnerable	Island
Thamnosophis stumpfii	Lamprophiidae; Pseudoxyrhophiinae	Vulnerable	Island
Pseudorabdion mcnamarae	Colubridae; Calamariinae	Vulnerable	Island

Pseudorabdion talonuran	Colubridae; Calamariinae	Vulnerable	Island
Dryocalamus philippinus	Colubridae; Colubrinae	Vulnerable	Island
Dryophiops philippina	Colubridae	Vulnerable	Island
Leptophis modestus	Colubridae; Colubrinae	Vulnerable	Continent
Lycodon paucifasciatus	Colubridae; Colubrinae	Vulnerable	Continent
Oligodon brevicauda	Colubridae; Colubrinae	Vulnerable	Continent
Oligodon juglandifer	Colubridae; Colubrinae	Vulnerable	Continent
Oligodon lacroixi	Colubridae; Colubrinae	Vulnerable	Continent
Oligodon modestus	Colubridae; Colubrinae	Vulnerable	Island
Oligodon pulcherrimus	Colubridae; Colubrinae	Vulnerable	Island
Orthriophis moellendorffi	Colubridae; Colubrinae	Vulnerable	Continent
Pseudorabdion mcnamarae	Colubridae	Vulnerable	Island
Pseudorabdion talonuran	Colubridae	Vulnerable	Island
Tantilla boipiranga	Colubridae; Colubrinae	Vulnerable	Continent
Tantilla jani	Colubridae; Colubrinae	Vulnerable	Continent
Tantilla psittaca	Colubridae; Colubrinae	Vulnerable	Continent
Tetralepis fruhstorferi	Colubridae; Colubrinae	Vulnerable	Island
Thelotornis usambaricus	Colubridae; Colubrinae	Vulnerable	Continent
Adelophis copei	Colubridae	Vulnerable	Continent
Adelphicos veraepacis	Colubridae; Dipsadinae	Vulnerable	Continent
Alsophis rufiventris	Colubridae; Dipsadinae	Vulnerable	Island
Atractus microrhynchus	Colubridae; Dipsadinae	Vulnerable	Continent
Atractus modestus	Colubridae; Dipsadinae	Vulnerable	Continent
Atractus nicefori	Colubridae; Dipsadinae	Vulnerable	Continent
Atractus paucidens	Colubridae; Dipsadinae	Vulnerable	Continent
Atractus roulei	Colubridae; Dipsadinae	Vulnerable	Continent
Calamodontophis paucidens	Colubridae; Dipsadinae	Vulnerable	Continent
Coniophanes dromiciformis	Colubridae; Dipsadinae	Vulnerable	Continent
Dipsas elegans	Colubridae; Dipsadinae	Vulnerable	Continent
Erythrolamprus atraventer	Colubridae; Dipsadinae	Vulnerable	Continent
Geophis juliai	Colubridae; Dipsadinae	Vulnerable	Continent
Geophis nephodrymus	Colubridae; Dipsadinae	Vulnerable	Continent
Haitiophis anomalus	Colubridae; Dipsadinae	Vulnerable	Island
Heterodon simus	Colubridae; Dipsadinae	Vulnerable	Continent
Hypsirhynchus scalaris	Colubridae; Dipsadinae	Vulnerable	Island
Ialtris haetianus	Colubridae; Dipsadinae	Vulnerable	Island
Omoadiphas aurula	Colubridae; Dipsadinae	Vulnerable	Continent
Philodryas livida	Colubridae; Dipsadinae	Vulnerable	Continent
Rhadinaea fulvittis	Colubridae; Dipsadinae	Vulnerable	Continent
Rhadinella montecristi	Colubridae; Dipsadinae	Vulnerable	Continent

Rhadinella pegosalyta	Colubridae; Dipsadinae	Vulnerable	Continent
Tantalophis discolor	Colubridae; Dipsadinae	Vulnerable	Continent
Hebius miyajimae	Colubridae; Natricinae	Vulnerable	Island
Storeria hidalgoensis	Colubridae; Natricinae	Vulnerable	Continent
Thamnophis gigas	Colubridae; Natricinae	Vulnerable	Continent
Thamnophis scaliger	Colubridae; Natricinae	Vulnerable	Continent
Tropidonophis negrosensis	Colubridae; Natricinae	Vulnerable	Island

CHAPTER 3

Snakes on roads – a case-study in the Savanna Biome of Limpopo Province, South Africa

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Formatted as a manuscript for submission to an international peer review journal

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Running header: Snakes on roads

3.1 ABSTRACT

Road mortality has long been recorded as having a serious impact on vertebrate and invertebrate fauna across the globe. The increasing network of roads into wilderness and protected areas is cause for concern. Studies have demonstrated that protected areas such as national parks and game reserves are not immune from the impact of road mortality with thousands of animals killed annually. Relatively little quantitive data exist on road-mortality

patterns and impacts on South African roads. Based on surveys carried out on the R516 road in the savanna biome of Limpopo Province, South Africa, we present baseline data on the impact of roads on the local snake fauna and highlight species composition from one stretch of road. The conservation implications are discussed.

Key words: Snake diversity; road kills; conservation.

3.2 INTRODUCTION

Snake population declines have been reported from across the globe (Reading et al., 2010). Road networks have been identified as a significant threat to biodiversity, both as a direct effect of vehicular collisions with wildlife, as well as the fragmentation effect road networks have on ecosystems and associated animal populations (Gibbons et al., 2000; Kioko et al., 2015). Numerous studies have focused on the impact of roads on animal populations, including reptiles and snakes which experience very high levels of road mortality (Rosen & Low, 1994; Gibson & Merkle, 2004; Row et al., 2007; Andrews et al., 2008; Jones et al., 2011; Kioko et al., 2015). Road ecology is an emerging and growing discipline in the ecological sciences and numerous mitigation measures have been researched and proposed, but the practicality of implementation is often inhibited by logistics and associated costs.

Limpopo Province is the northernmost province in the Republic of South Africa and much of the province falls within the savanna biome, with fragmented grassland occurring mostly along the eastern escarpment (Mucina & Rutherford, 2006). Approximately 83 snake taxa (species and subspecies) have been recorded within the province. Of these, 58 taxa are known from the Central Bushveld Bioregion (Egan, 2006; Bates et al., 2014).

There are no comprehensive studies published on snake road mortality in southern Africa. This study provides some baseline data on road mortality on a snake community in the

savanna biome of South Africa and possible long-term impacts roads may have on herpetofauna. It highlights the devastating impact roads can have on snakes and its implications for conservation. Based on preliminary results, a downward trend in number of snakes encountered in consecutive periods demonstrates a decline in snakes. However, results still need to be tested empirically using statistical methodology and comparative studies from other regions and roads are needed to quantify the true impact roads and vehicular traffic have on snakes and other vertebrates.

3.3 METHODS

3.3.1 Description of study site

The R516 is a national road situated in Limpopo Province of South Africa (Figure 3S.1). It transects the Central Bushveld Bioregion in the Savanna Biome (Mucina & Rutherford, 2006) and runs just south of the Waterberg Biosphere Reserve. At least three vegetation units occur as an interlinking mosaic along the R516: SVcb12: Central Sandy Bushveld; SVcb15: Springbokvlakte Thornveld (mostly around the town of Belabela) and SVcb16: Western Sandy Bushveld (mostly on the western sections of the R516). The surrounding hills and mountain ranges comprise SVcb17: Waterberg Mountain Bushveld. Dominant tree species include *Terminalia sericea*, *Burkea africana* and several *Vachellia* species (Mucina & Rutherford, 2006). These vegetation units blend into each other along the R516 and snake species composition was not influenced by a particular vegetation unit, and therefore not discussed further. Much of the area consists of natural vegetation, however, several agricultural farms occur along the R516, but in recent years much of the area has reverted to game farming. Altitude along the R516 road varies between 1000 m to 1276 m a.s.l.

For the purposes of our study, the R516 was divided into five segments and designated a reference code as follows. The R516E (a section of approximately 20 km running east of the

N1); the R516A (the portion running west between the N1 and the town of Belabela); the R516W/S1 (approximately 34 km west from the town of Belabela to the Mabula turn-off); the R516W/S2 (approximately 33 km between the Mabula and Rooiberg roads); and the R516W/S3 (running from Rooiberg to the Thabazimbi T-junction). In addition, two further roads were surveyed: the tarred road leading to Rooiberg (approximately 24 km) and the Mabula-Rooiberg sand (dirt) road (approximately 30km) (Figure 3.1). These designated sections were noted for control purposes during data gathering.

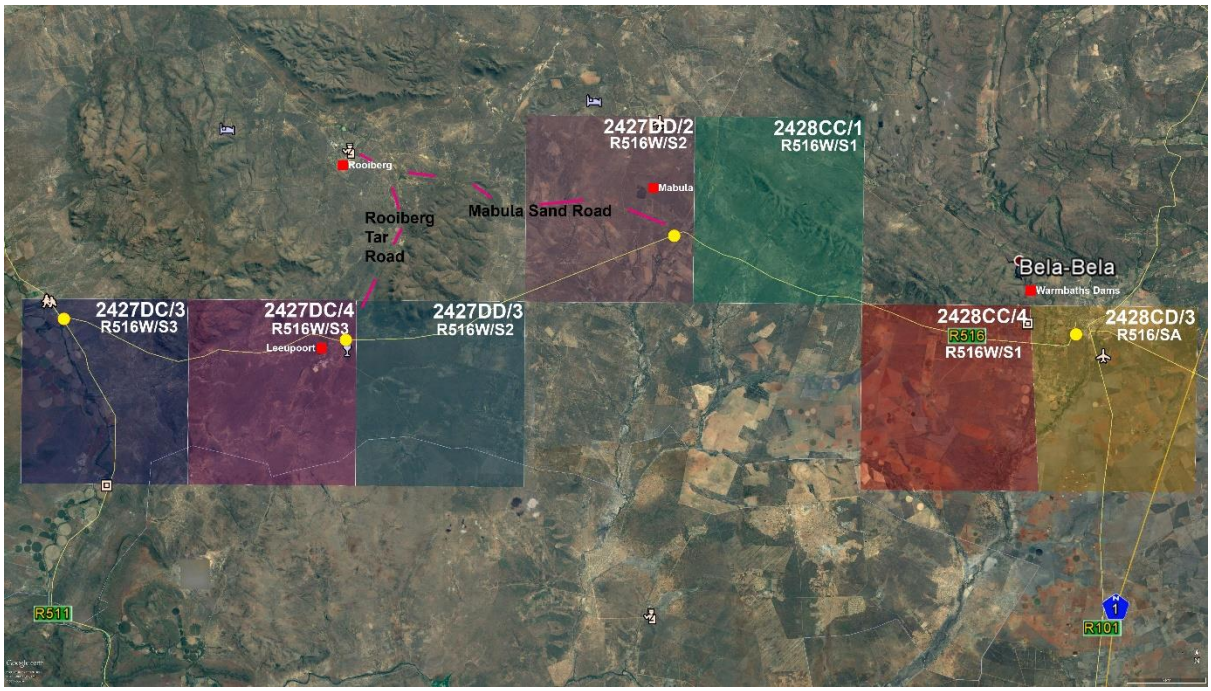

Figure 3.1: A Google Earth satellite image showing eighth-degree grid overlays along the R516 road in Limpopo Province, South Africa. The road network was divided into measurable sections.

3.3.2 Data collection

During the period December 1994 to December 2015, 46 random surveys were conducted along the R516 with the objective of finding and documenting live and road-killed snakes (see Schmidt & Olsen, 1999; Table 3.1). A vehicle was driven at an average speed of 30-40 km per hour. Most surveys were carried out after sunset; however, a few were conducted during

daylight, mostly as follow-up surveys. Initial attempts at recording temperature, humidity and atmospheric pressure were aborted due to the unreliability of existing instrumentation and the large disparity between surface temperature and air temperature, which may have great impact on activity patterns in a terrestrial ectothermic vertebrate whose entire ventral surface in in contact with the substrate (Dorcas & Willson, 2009). This would have provided speculative data at best about under which environmental conditions snake activity occurred. However, activity time and general weather conditions were noted, as well as moon-phase.

Snakes were positively identified to species and where possible and practical, sex and length were recorded. Several representative road-killed vouchers were collected and deposited in the herpetological collection of the Ditsong Natural History Museum, Pretoria (formerly the Transvaal Museum), as well as several rare or little-known species found dead-on-the-road.

Mileage and survey dates and times were recorded, however, each survey was random and not pre-planned, as field time would be reliant on available time and finances. Most surveys were carried out from October to January which is the height of the summer rainfall season in Limpopo Province (Figure 3.1) and deemed to yield the highest success rate in species detection.

Coordinate locality points were taken for all snakes encountered. During earlier surveys, these were carefully plotted on government issued 1: 50 000 topographical maps and later using a hand-held Garmin global positioning system (GPS).

Simple descriptive statistics and correlations were conducted with Statistica (Statsoft, Tulsa, OK).

Table 3.1: R516 road near Belabela, Limpopo Province, detailing survey dates and times.

Date:	Duration:	Mileage in km (approx.):	Snakes alive:	Snakes DOR:	Notes:
06/12/1994 Tue	18h30-00h30 (6 h)	108km	2	3	**Survey 1:** Paul Olsen, Liam Bebbington, Warren Schmidt. NIGHT; New Moon; Warm and dry weather conditions.
16/12/1994 Fri	20h00-23h00 (3 h)	152km	1	2	**Survey 2:** Paul Olsen, Ian, Warren Schmidt. NIGHT; Full Moon; Overcast but warm.
02/01/1995 Mon	19h30-00h00 (4.5 h)	182km	1	8	**Survey 3:** Warren Schmidt, Jason McLennan. NIGHT; New Moon; Hot and humid conditions.
06/01/1995 Fri	20h00-22h00 (2 h)	86km	0	1	**Survey 4:** Paul Olsen, Grant Linton. NIGHT; First Quarter.
26/01/1995 Thu	19h30-23h30 (4 h)	152km	4	2	**Survey 5:** Paul Olsen, Warren Schmidt. NIGHT; Last Quarter; Very warm weather conditions.
04/02/1995 Sat	19h00-23h00 (4 h)	168km	0	5	**Survey 6:** Warren Schmidt. NIGHT; First Quarter
06/05/1995 Sat	18h00-01h30 (5.5 h)	192km	1	12	**Survey 7:** Paul Olsen, Warren Schmidt. NIGHT; First Quarter; Recent rains but warm.
21/09/1995 Thu	20h30-01h00 (4.5 h)	152km	3	7	**Survey 8:** Paul Olsen, Warren Schmidt. NIGHT; New Moon; Weather warm.
09/10/1995 Mon	17h30-22h30 (5 h)	186km	5	11	**Survey 9:** Warren Schmidt. NIGHT; Full Moon; Warm and overcast.
26/10/1995 Thu	19h00-22h00 (3 h)	160km	0	3	**Survey 10:** Paul Olsen, Grant Linton. NIGHT; New Moon.
02/11/1995 Thu	20h00-23h00 (3 h)	152km	0	7	**Survey 11:** Paul Olsen, Warren Schmidt. NIGHT; First Quarter.
12/11/1995 Sat	15h00-00h00 (9 h)	207km	5	11	**Survey 12:** Paul Olsen, Warren Schmidt. DAY/NIGHT; Last Quarter; Very hot weather conditions.
05/01/1996 Fri	22h00-01h00 (3 h)	152km	3	3	**Survey 13:** Paul Olsen, Warren Schmidt. NIGHT; Full Moon; Cloudy with heavy rainfall.
31/01/1996 Wed	20h30-01h30 (5 h)	160km	2	1	**Survey 14:** Paul Olsen, Liam Bebbington, Phil Wright, Warren Schmidt. NIGHT; First Quarter.
16/04/1996 Tue	18h00-21h00 (3 h)	168km	0	4	**Survey 15:** Paul Olsen, Warren Schmidt. NIGHT; New Moon.
23/08/1996 Fri	20h00-22h00 (2 h)	93km	0	0	**Survey 16:** Jason McLennan, Warren Schmidt. NIGHT; First Quarter.
01/10/1996 Tue	20h30-00h30 (4 h)	186km	4	4	**Survey 17:** Paul Olsen, Tina Bebbington, Warren Schmidt. NIGHT; Last Quarter; Clear and warm conditions; temperature 27-24°C.
06/10/1996 Sun	18h00-00h00 (6 h)	216km	3	15	**Survey 18:** Warren Schmidt. NIGHT; Last Quarter; Hot with no rain.
14/10/1996 Mon	19h30-00h30 (5 h)	186km	3	7	**Survey 19:** Doug Lee, Warren Schmidt. NIGHT; New Moon; Warm and humid with sporadic rainfall later in the evening.
07/11/1996 Thu	18h00-00h00 (6 h)	207km	5	8	**Survey 20:** Paul Olsen, Liam Bebbington, Warren Schmidt. NIGHT; New Moon; Warm.

27/01/1997 Mon	20h00-23h00 (3 h)	152km	0	2	**Survey 21:** Paul Olsen, Warren Schmidt. NIGHT; Full Moon; Raining.
01/02/1997 Sat	18h00-00h30 (6.5 h)	186km	3	5	**Survey 22:** Warren Schmidt. NIGHT; Last Quarter; Hot.
24/09/1997 Wed	20h00-22h00 (2 h)	100km	0	0	**Survey 23:** Warren Schmidt. NIGHT; Last Quarter.
27/10/1997 Sun	22h00-23h00 (1 h)	84km	0	2	**Survey 24:** Warren Schmidt. Passing through. NIGHT; Last Quarter.
17/11/1998 Tue	19h00-23h00 (4 h)	168km	2	6	**Survey 25:** Brent B., Warren Schmidt. NIGHT; New Moon.
17/04/1999 Sat	17h00-19h00 (2 h)	68km	0	0	**Survey 26:** Dewet Espach, Lizelle Ferreira, Warren Schmidt. NIGHT; New Moon.
10/10/1999 Sun	17h00-21h00 (4 h)	134km	0	0	**Survey 27:** Warren Schmidt. NIGHT; New Moon.
09/10/2000 Mon	19h00-23h00 (4 h)	152km	2	1	**Survey 28:** Warren Schmidt. NIGHT; First Quarter; Warm and dry conditions; temperature 23-22°C.
14/11/2000 Tue	21h00-23h00 (2 h)	93km	0	0	**Survey 29:** Warren Schmidt. Road trip back from Sun City via R516. NIGHT; Full Moon.
03/12/2000 Sun	18h00-21h00 (3 h)	186km	1	2	**Survey 30:** Justin Schmidt, Warren Schmidt. NIGHT; First Quarter.
11/12/2000 Mon	19h00-21h00 (2 h)	116km	0	2	**Survey 31:** Warren Schmidt. NIGHT; Full Moon.
04/03/2001 Sun	19h00-21h00 (2 h)	196km	1	1	**Survey 32:** Justin Schmidt, Warren Schmidt. NIGHT; First Quarter.
09/12/2001 Sun	11h00-14h30 (3.5 h)	173km	0	3	**Survey 33:** Warren Schmidt. DAY; Last Quarter.
09/12/2001 Sun	19h00-22h00 (3 h)	113km	2	1	**Survey 34:** Warren Schmidt. NIGHT; Last Quarter.
28/12/2004 Tue	07h30-12h30 (5 h)	189km	0	0	**Survey 35:** Anthony Schmidt, Warren Schmidt. DAY.
28/12/2004 Tue	18h00-22h00 (4 h)	134km	0	1	**Survey 36:** Anthony Schmidt, Warren Schmidt. NIGHT; Full Moon.
06/01/2007 Sat	20h00-02h00 (6 h)	236km	3	7	**Survey 37:** Jens Reissig, Colleen Tiedemann, Warren Schmidt. NIGHT; Full Moon.
14/10/2007 Sun	16h00-19h00 (3 h)	152km	0	4	**Survey 38:** Jens Reissig, Colleen Tiedemann, Warren Schmidt. NIGHT; Full Moon.
10/11/2007 Sat	19h00-23h00 (4 h)	192km	0	1	**Survey 39:** Warren Schmidt. NIGHT; New Moon.
10/11/2009 Tue	19h00-22h00 (3 h)	93km	0	1	**Survey 40:** Jason McLennan, Warren Schmidt. Driving from Pilanesberg side. NIGHT; Last Quarter.
12/12/2009 Sat	22h00-00h00 (2 h)	100km	0	0	**Survey 41:** Jens Reissig, Colleen Tiedemann, Warren Schmidt. NIGHT; New Moon.
03/11/2011 Thu	20h00-22h00 (2 h)	86km	0	0	**Survey 42:** Warren Schmidt. NIGHT; First Quarter.
24/11/2011 Thu	19h30-21h30 (2 h)	80km	0	0	**Survey 43:** Warren Schmidt. Heavy rains, dangerous road conditions. Aborted at 21h30 after near miss with large truck and almost rolling vehicle. NIGHT; New Moon.
28/10/2012 Sun	13h00-14h00 (1 h)	73km	0	0	**Survey 44:** Warren Schmidt. Passing through, but carried out visual survey.

					No snakes seen. DAY; Full Moon; Heavy rains over last 24 h.
20/12/2013 Fri	06h00-13h00 (7 h)	133km	0	0	**Survey 45:** Lukas Otto, Warren Schmidt. DAY; Full Moon; Daylight survey cross-referencing data. Warm and sunny.
20/12/2015 Sun	21h00-22h00 (1 h)	50km	0	0	**Survey 46:** Warren Schmidt. NIGHT; First Quarter; Survey aborted after one hour. Extremely heavy traffic and dangerous conditions.
TOTAL:	**169.5 h**	**6 704 km**	**56 live**	**153 DOR**	**209 snakes recorded in total during 46 surveys.**

3.4 RESULTS

Approximately 6 704 km were travelled in total equating to 170 h of survey effort (Table 3.1). A total of 209 snakes comprising 27 species were recorded from the study site. This represented approximately 46.5% of taxa recorded from the Central Bushveld Bioregion. Of these 153 snakes (73.2%) were recorded as road-killed (DOR) and 56 (26.8%) were found alive (Table 3.2, Figure 3.2). All snakes were positively identified to species (Figure 3S.2).

Table 3.2: Number and species diversity of snakes encountered on the R516 and surrounding roads mentioned in this study, depicting number found alive and dead-on-road (DOR), listed from highest to lowest.

Species:	Alive:	DOR:	Total:
Bitis arietans arietans Puff Adder (Viperidae)	3	32	35
Dasypeltis scabra Common/Rhombic Egg-eater (Colubridae)	11	20	31
Boaedon capensis Common/Brown House Snake (Lamprophiidae; Lamprophiinae)	10	17	27
Naja (Afronaja) mossambica Mozambique Spitting Cobra (Elapidae)	3	18	21
Crotaphopeltis hotamboeia Red-lipped/Herald Snake (Colubridae)	8	11	19
Atractaspis bibronii Bibron's Stiletto Snake (Atractaspididae; Atractaspidinae)	7	5	12
Psammophis brevirostris Short-snouted Grass Snake (Lamprophiidae; Psammophiinae)	1	9	10
Naja (Uraeus) annulifera Snouted Cobra (Elapidae)	0	8	8
Gonionotophis capensis capensis Common File Snake (Lamprophiidae; Lamprophiinae)	0	7	7
Python natalensis Southern African Python (Pythonidae)	0	6	6
Aparallactus capensis Cape Centipede-eater (Atractaspididae; Aparallactinae)	3	1	4
Dispholidus typus viridis Savanna Boomslang (Colubridae)	0	4	4
Prosymna bivittata Two-striped Shovel-snout (Lamprophiidae; Prosymnidae)	3	0	3

Telescopus semiannulatus semiannulatus Eastern Tiger Snake (Colubridae)	0	3	3
Atractaspis duerdeni Duerden's Stiletto Snake (Atractaspididae; Atractaspidinae)	2	0	2
Causus defilippii Snouted Night Adder (Viperidae)	0	2	2
Dendroaspis polylepis Black Mamba (Elapidae)	0	2	2
Lycophidion capense capense Cape Wolf Snake (Lamprophiidae; Lamprophiinae)	1	1	2
Pseudaspis cana Mole Snake (Lamprophiidae; Pseudaspidinae)	1	1	2
Xenocalamus bicolor australis Waterberg Quill-snouted Snake (Atractaspididae; Aparallactinae)	0	2	2
Amblyodipsas polylepis polylepis Common Purple-glossed Snake (Atractaspididae; Aparallactinae)	1	0	1
Aspidelaps scutatus scutatus Western Shield-nose Snake (Elapidae)	1	0	1
Bitis caudalis Horned Adder (Viperidae)	0	1	1
Psammophis subtaeniatus Western Stripe-bellied Sand Snake (Lamprophiidae; Psammophiinae)	0	1	1
Psammophylax tritaeniatus Three-striped Grass Snake (Lamprophiidae; Psammophiinae)	0	1	1
Rhinotyphlops lalandei Delalande's Beaked Blind Snake (Typhlopidae)	1	0	1
Thelotornis capensis capensis South-eastern Savanna Vine Snake (Colubridae)	0	1	1
TOTAL:	**56**	**153**	**209**

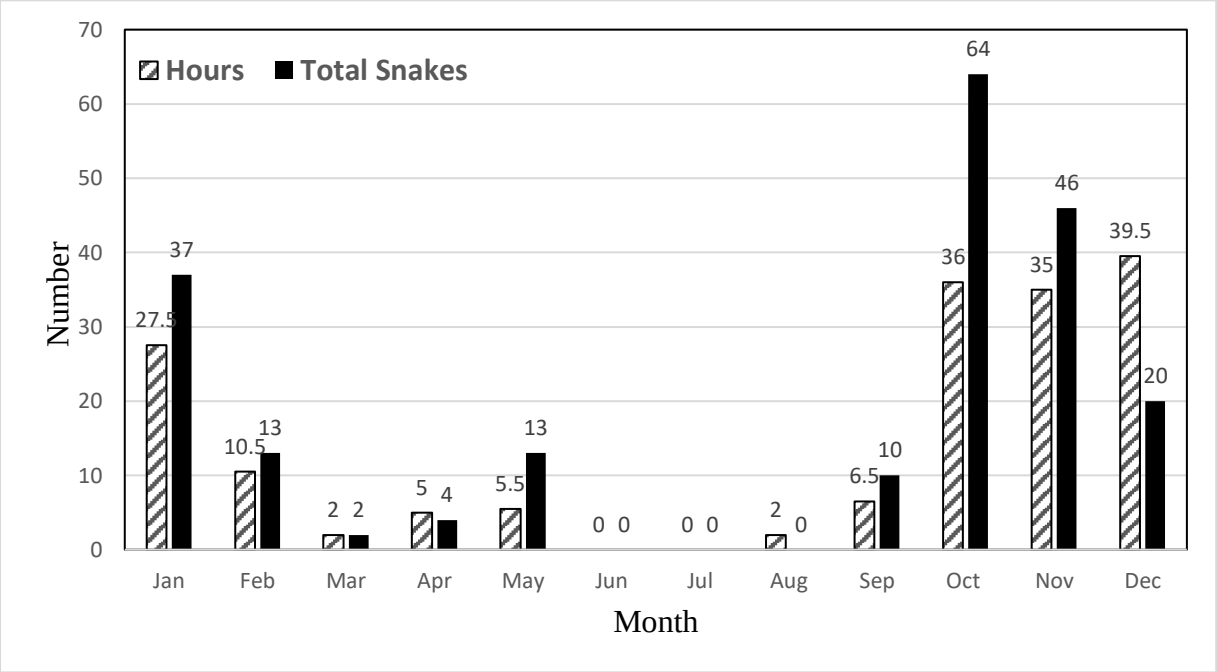

Figure 3.2: Combined survey months across all 46 surveys showing total hours and total snakes found. Surveys were aimed largely during the summer months during peak rainfall season.

Snakes were sampled spatially across the surveyed roads and there were no discernible sections where snake density appeared higher than elsewhere (Figures 3.3 and 3.4). The four most commonly encountered snake species were evenly distributed across all vegetation types in the present study (Figure 3.5). All four represent different families: Viperidae, Colubridae, Lamprophiidae and Elapidae (Figure 3.5). October appeared to be the most successful survey period in relation to individual snakes found measured against search effort (time): 64 snakes recorded during 36 h of surveying (Figure 3.2). This coincided with the start of the rainy season and increased ambient temperatures, after a period of brumation when snake activity is low (June to August). Detectability remained high in relation to search hours throughout November, December and January. Reduced rates were recorded in the months of February, March and April, however, this was strongly biased towards decreased survey effort and activity may remain high, as 13 snakes were recorded during May in only 5.5 h of search effort (Figure 3.2).

Puff adders *Bitis arietans arietans* were the most recorded snakes in the study area with high mortality rates (32 road-killed snakes out of 35 encountered, Table 3.2). This was not surprising as these snakes are relatively common in the savanna biome (Branch, 1998; WRS pers. obs., various pers. comm.). Males are particularly active during the breeding season and puff adders are relatively slow-moving snakes. Some have been observed thermoregulating on the warm tarred surface and when detected when actively crossing a road, often freeze at the approach of a vehicle (WRS pers. obs.).

The next two most commonly encountered snakes were rhombic egg-eaters *Dasypeltis scabra* (31 records with 64.5% mortality) and brown house snakes *Boaedon capensis* (27 records with 62.9% mortality, Table 3.2). Both species are common in the savanna biome and primarily nocturnal and largely terrestrial, although *Dasypeltis scabra* is partially arboreal when searching out eggs in elevated bird nests (Branch, 1998).

Mozambique spitting cobras *Naja (Afronaja) mossambica* comprised 21 records with 85.7% mortality (Table 3.2). These snakes are common in the savanna biome and readily adapt to human infrastructure such as buildings and farms (WRS pers. obs.) and readily live near humans. They are known to scavenge dead animals and may be attracted to roads in search of road-killed toads and snakes (Branch, 1998). The red-lipped or herald snake *Crotaphopeltis hotamboeia* is yet another common terrestrial, nocturnal species (Table 3.2; Branch, 1998). Although their diet includes mostly amphibians, including toads, they are known to include small lizards in their diet and therefore not confined entirely to wetlands (Branch, 1998).

Southern African pythons *Python natalensis* appear to be another species heavily impacted by roads (six records with 100% mortality, Table 3.2). These snakes are both nocturnally and diurnally active and reasonably slow-moving (Branch, 1998). Interestingly, two hatchling pythons were recorded dead-on-road in close proximity on the same evening on 1 February 1997. They were presumed to have hatched from the same nest as both had the umbilical ventral slit and 'egg-tooth' was clearly visible and the snakes were of the same size.

Diurnally active snakes were less commonly encountered (Table 3.2). These included the sand or grass snakes (*Psammophis sp.*), boomslang *Dispholidus typus* and black mamba *Dendroaspis polylepis*. All these snakes are fast-moving, active hunters and may therefore cross open roads more swiftly than their slower moving nocturnal counterparts (Branch, 1998). However, short-snouted grass snakes *Psammophis brevirostris* were frequently recorded (10 records with 90% mortality). Diurnal scavengers, such as certain raptors and crows, may remove road-killed snakes from the road before they are encountered and therefore detection rates for diurnal species may be much lower (see discussion below). However, based on the numerous records amassed for road-killed agamas (*Acanthocercus* spp.), monitor lizards (*Varanus* spp.), and chameleons (Chamaeleonidae), many of which were a few days old and

completely compressed, it appears that road-killed diurnally active reptiles are not scavenged as frequently as suggested (WRS pers. obs.).

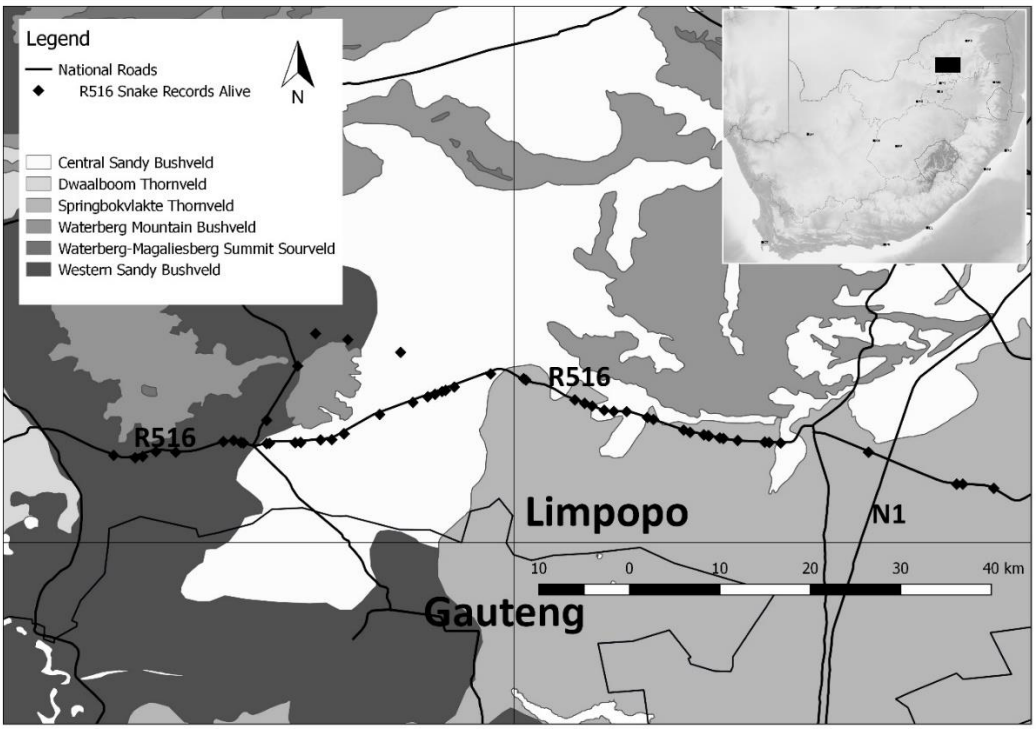

Figure 3.3: Map showing locality points along the R516 road of all live snakes encountered, with a vegetation type overlay in the present study**.**

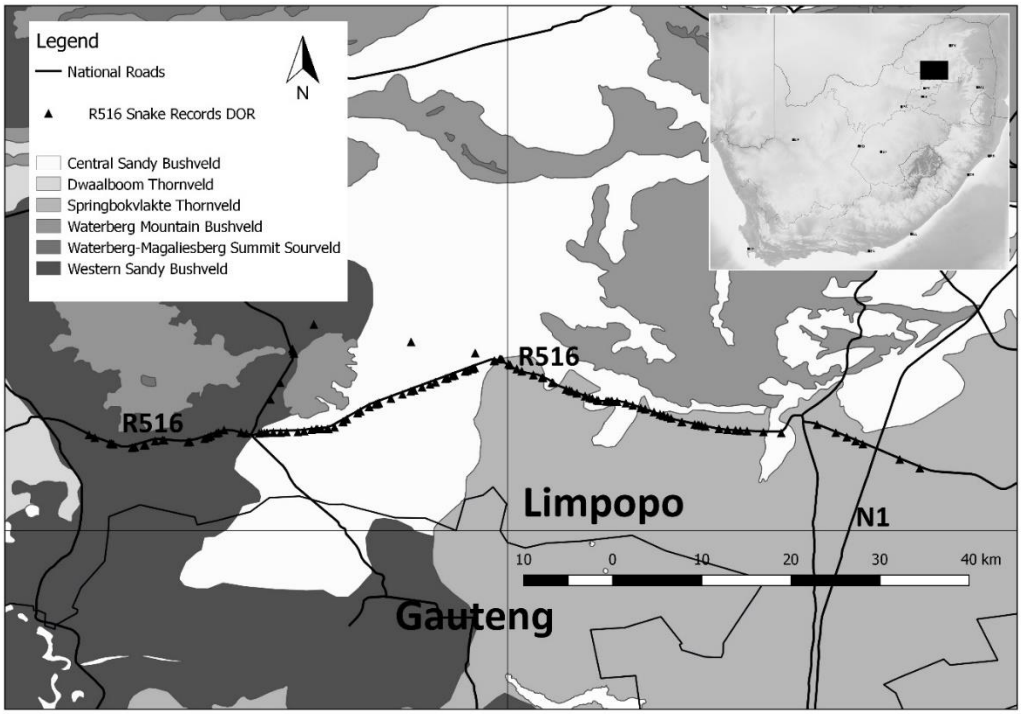

Figure 3.4: Map showing locality points of all road-killed snakes encountered along the R516 with a vegetation type overlay in the present study.

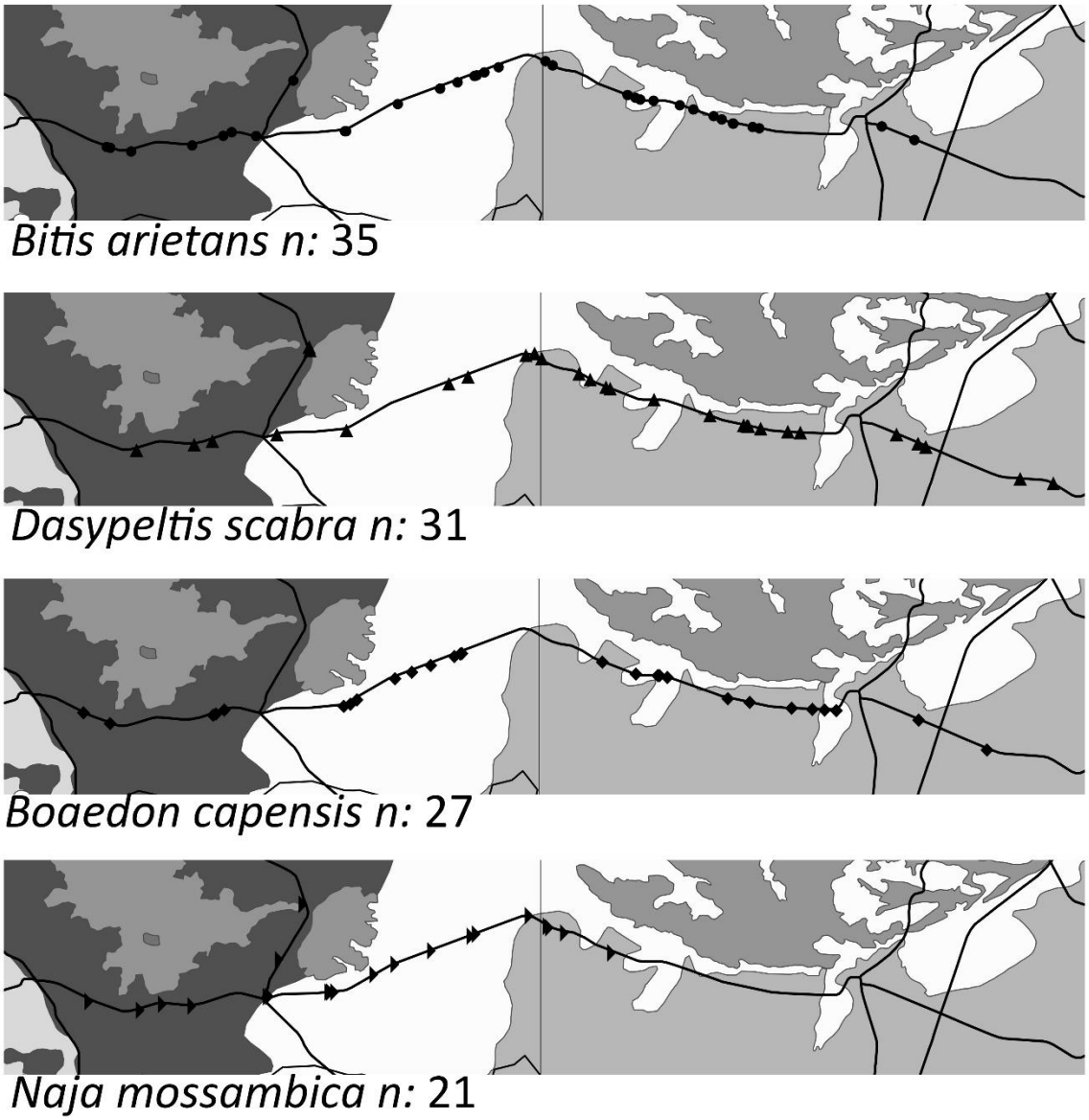

Figure 3.5: The four most commonly encountered snake species which were evenly distributed across all vegetation types in the present study. All four represent different families: Viperidae, Colubridae, Lamprophiidae and Elapidae respectively. (For location and scale bar, see Figures 3.3 and 3.4 above).

3.4.1 Perceived declines

Surveys were divided into four equal times periods:

Part 1: 38.5 search hours (Surveys 1 - 9) = 68 snakes [1994/1995]

Part 2: 38 search hours (Surveys 10 - 18) = 65 snakes [1995-1996]

Part 3: 39.5 search hours (Surveys 19 - 29) = 46 snakes [1996-2000]

Part 4: 39.,5 search hours (Surveys 30 - 46; excluding 35, 44 and 45) = 30 snakes [2000-2011]

An analysis of snakes encountered during these consecutive time periods showed a significant steady decline in number of snakes encountered (Figure 3.6; correlation, r = - 0.97, P < 0.05). Three daylight surveys were excluded from this analysis to avoid bias and only nocturnal surveys included. The broad timeframe across different climatic variables should rule out any bias relating to climatic or thermal preferences influencing snake activity. However, historical climate data will need to be incorporated into the analysis.

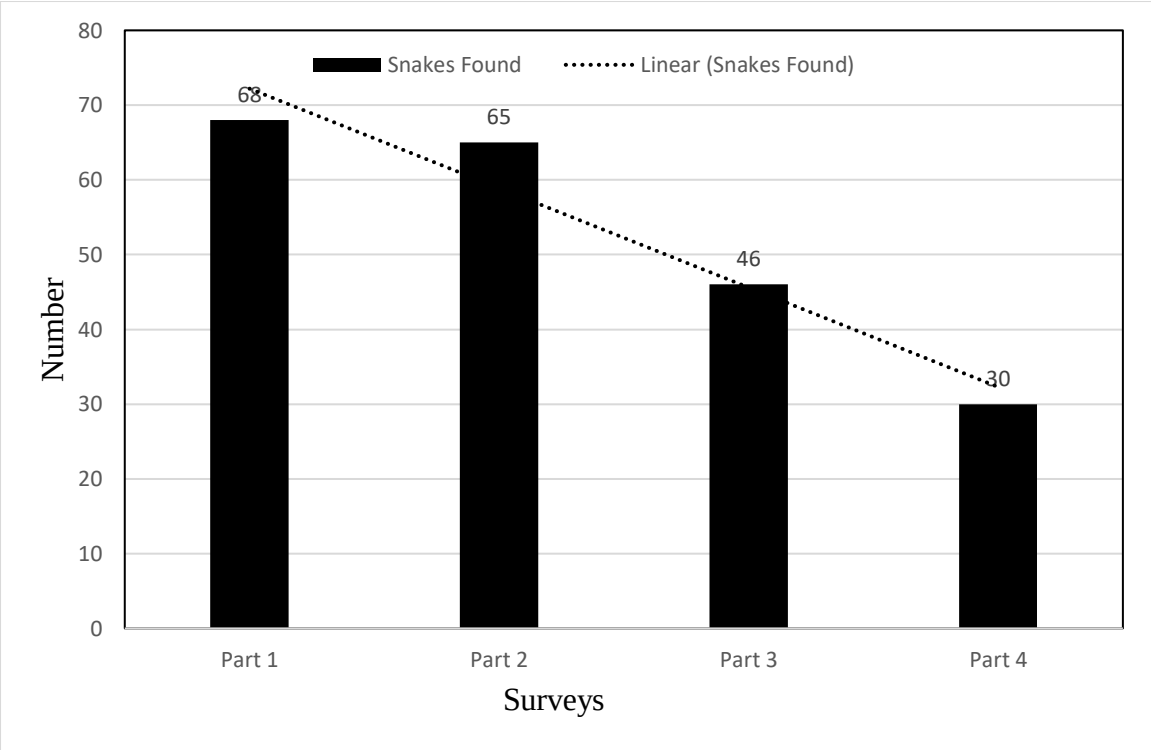

Figure 3.6: Consecutive surveys divided into four equal portions in hours showing extent of decline in snake occurrence. (Note: Surveys 35, 44 and 45 were removed to avoid bias, as these were conducted during daylight, whereas the others were nocturnal surveys). (Part 1: 38.5 search hours (Surveys 1 - 9) = 68 snakes [1994/1995]; Part 2: 38 search hours (Surveys 10 - 18) = 65 snakes [1995-1996]; Part 3: 39.5 search hours (Surveys 19 - 29) = 46 snakes [1996-

2000]; Part 4: 39.5 search hours (Surveys 30 - 46; excluding 35, 44 and 45) = 30 snakes [2000-2011])

3.5 DISCUSSION

Direct road mortality on animal communities and the demographic effect on surrounding populations are acknowledged as a serious conservation concern and leading to increased studies in the field of road ecology (van der Grift et al., 2013; Kioko et al., 2015).

The above study, although not conclusive, provides baseline data on the effects of road traffic on savanna snakes. Further robust studies examining snake activity patterns are required to elucidate the long-term impact roads might have on surrounding snake communities. There are relatively few long-term ecological studies on southern African snakes and therefore determining how often and when snakes are subject to increased road mortality remain subjective.

Comparative studies in North America, Europe and Australia have shown that there is often a strong disparity between natural vegetation units, agricultural cultivation or wetlands alongside roads which influence snake demographics (Andrews et al., 2008; Kioko et al., 2015). This does not appear to be the case on the R516 where the most commonly encountered species were spread randomly along the length of the R516.

Several attempts have been made to elucidate the impact of road mortality on snakes using various computational statistical methods. Rosen and Lowe (1994) presented an algebraic method to calculate road mortality in the Organ Pipes National Monument in Arizona. This study estimated that 2838 snakes are killed annually along 13.5 km of road. Gibson and Merkle (2004) looked at road mortality in Virginia. This study also demonstrated a high impact on local snakes with the two most commonly encountered roadkill snakes

including eastern ratsnakes (*Pantherophis alleghaniensis*) and rough green snakes (*Opheodrys aestivus*).

Accurate estimates of roadkills may be difficult to quantify, as several studies have shown that many snakes are removed by scavengers before surveys are conducted. DeGregorio et al. (2011) placed snake carcasses randomly across selected locations along a 2 km stretch of road and showed that up to 50% of carcasses were removed from the road surface by scavengers within 8 h, mostly at night. Therefore, surveying roads during daylight hours for roadkill may greatly underestimate the impact of road traffic on smaller vertebrate animals such as amphibians, rodents and reptiles. Another comparative study was conducted by Hubbard and Chalfoun (2012) in southwest Wyoming which also found that a significant number of carcasses were removed off the road by scavengers. Along the R516, several black-backed jackals (*Canis mesomelas*), small-spotted genets (*Genetta genetta*) and an aardwolf (*Proteles cristatus*) have been found as road-kill, indicating that these mammals might have been scavenging for road-kill and had a delayed response to oncoming vehicles. In the present study mortality rates of Mozambique spitting cobras and snouted cobras (*Naja annulifera*) may be elevated as they attempt to scavenge dead amphibians and other snakes from the road surface. Recent radio-telemetry studies (Glaudas & Alexander, 2016) have provided much insight into seasonal activity patterns and movement of puff adders and these data should be extrapolated to determine the impact of roads on puff adders and whether current mortality rates are viable to long-term population viability. Puff adders are largely nocturnal, and the data in the present study supported this, although activity may be seasonal with diurnal activity dominating during the cooler winter months.

We attribute the decline in snakes in the present study to greatly increased traffic volumes in latter years. Whether the decline is a result of local snake population decline due to increased road mortality or road avoidance is unknown. The latter hypothesis seems unlikely.

The assumption that snakes are adapting strategies to avoid roads under such a short evolutionary time period is doubtful, but this would show an interesting line of enquiry. It's more conceivable that mammals and birds may avoid roads due to increased traffic volume which may scare them away. But snakes being low down terrestrially and deaf to airborne sound, and generally having poor eyesight, may not be as perceptive to traffic movement as birds and mammals. The effect of vibrational frequencies from passing traffic and its impact on snakes is unknown but likely to be minimal on a tarred surface. A theory previously proposed by a former colleague was that snakes are attracted to roads by vehicular lights, but this seems highly doubtful. In published studies, snakes have been found to cross over roads during mate searching, foraging or simply that the road intersects their normal home ranges (Rosen and Low, 1994; Andrews et al., 2008; Jochimsen et al., 2014). Large bodied snakes such as adders and vipers may use the warm surface for thermoregulation, therefore increasing their risk of mortality, as highlighted with puff adders in this study.

Road networks have also been shown to interrupt dispersal of certain snake species such as timber rattlesnakes (*Crotalus horridus*) in North America, resulting in genetic isolation (Clark et al., 2009). This is certainly a concern for larger bodied, more sedentary species such as adders and vipers, especially in more temperate climates where increased movement is largely seasonal and can result in high mortality over a fairly short period.

Based on published studies and this study, roads have a detrimental and direct impact on snakes and snake populations. The long-term impact on snake population viability is unknown, but preliminary evidence suggests that many snake populations have declined dramatically in regions of high traffic volume (Jones et al., 2011; Jochimsen et al., 2014; this study). Mitigation measures are relatively difficult to implement, and traffic volumes and new road networks are likely to increase in the foreseeable future. Further research into road ecology is urgently needed, especially in South Africa where the topic has been largely neglected. The

Endangered Wildlife Trust set up the Wildlife and Roads Project which is commendable. This project is currently investigating the impact of roads on wildlife and promoting the field of road ecology in South Africa. Further research is required to determine which species are most vulnerable to road mortality and if the different biomes have greater or lesser impacts. For example, snakes on roads and associated road mortality appears to be much higher in the Savanna, Desert and Succulent Karoo Biomes, compared with the Grassland Biome (WRS pers. obs.). However, this could be a result of increased search effort (i.e. road-cruising) in these biomes compared with the Grassland Biome. Species lifestyle traits that demonstrate increased road-mortality require further investigation. The impact on roads may vary regionally and seasonally, and mitigation measures can be focused on areas where vulnerable species are most at risk.

3.6 ACKNOWLEDGEMENTS

WRS would like to thank the following who participated in surveys: The late P. Olsen, who jointly initiated our pioneering work along the R516. The late D. Espach and P. Wright who accompanied us on field excursions. L. Bebbington, T. Bebbington, G. Linton, J. McLennan, D. Lee, B. Botha, L. Botha, J. Reissig, C. Tiedemann, L. Otto, A. Schmidt and J. Schmidt all assisted in various surveys. W. Haacke (formerly of Transvaal Museum) is thanked for assistance in accessioning important road-killed specimens. The late R. Newbury (North West Parks & Tourism Board) is thanked for discussions on snakes on roads and encouraging our earlier studies. Various conservation officials in the transitionary Northern Province/Limpopo Nature Conservation Department are acknowledged for support and discussions regarding snake road mortality in the province. We are grateful to the University of KwaZulu-Natal and the National Research Foundation (ZA) for funding CTD.

3.7 REFERENCES

Andrews, K. M. & Whitfield Gibbons, J. 2005. How do highways influence snake movement? Behavioural response to roads and vehicles. *Copeia* 2005 (4): 772-782.

Andrews, K. M., Whitfield Gibbons, J. & Jochimsen, D. M. 2008. Ecological effects of roads on amphibians and reptiles: a literature review. In *Urban Herpetology, Herpetological Conservation* 3: 121-143.

Bates, M.F., Branch, W.R., Bauer, A.M., Burger, M., Marais, J., Alexander, G.J., & De Villiers, M.S (eds). 2014. Atlas and Red List of the Reptiles of South Africa, Lesotho and Swaziland. *Suricata* 1. South African National Biodiversity Institute, Pretoria.

Chittaragi, J. B. & Hosetti, B. B. 2014. Road kill mortality of snakes (Squamata: Serpentes) in different land cover areas of Semi-Malnad region, Mid Western Ghats, Shimoga, India. *Current Biotica* 8 (1): 57-65.

Clark, R. W., Brown, W. S., Stechert, R. & Zamudio, K. R. 2009. Roads, interrupted dispersal and genetic diversity in timber rattlesnakes. *Conservation Biology* 24 (4): 1059-1069. Doi:10.1111/j.1523-1739.2009.01439.x

Covaciu-Marcov, S-D., Ferenti, S., Ghira, I. V. & Sas, I. 2012. High road mortality of *Dolichophis caspius* in southern Romania. Is this a problem? What can we do? *North Western Journal of Zoology* 8 (2): 370-373.

D'Amico, M., Román, J., de los Reyes, L. & Revilla, E. 2015. Vertebrate road-kill patterns in Mediterranean habitats: who, when and where. *Biological Conservation* 191: 234-242. http://dx.doi.org/10/1016/j.biocon.2015.06.010

DeGregorio, B. A., Nordberg, E. J., Stepanoff, K. E. & Hill, J. E. 2010. Patterns of snake road mortality on an isolated barrier island. *Herpetological Conservation and Biology* 5 (3): 441-448.

DeGregorio, B.A., Hancock, T. E., Kurz, D. J. & Yue, S. 2011. How quickly are road-killed snakes scavenged? Implications for underestimates of road mortality. *Journal of the North Carolina Academy of Science* 127(2): 184-188.

Egan, V. 2006. Geographical Distribution: *Amblyodipsas ventrimaculata* (Roux, 1907) Kalahari Purple-glossed Snake. African Herp News 41: 26.

Garriga, N., Santos, X., Montori, A., Richter-Boix, A., Franch, M. & Llorente, G. A. 2012. Are protected areas truly protected? The impact of road traffic on vertebrate fauna. *Biodiversity Conservation* 21: 2761-2774. Doi: 10.1007/s10531-012-0332-0.

Gibson, J. D. & Merkle, D. A. 2004. Road mortality of snakes in central Virginia. *Banisteria* 24: 8-14.

Glaudas, X. & Alexander, G. J. 2016. Food supplementation affects the foraging ecology of a low-energy, ambush-foraging snake. *Behavioural Ecology and Sociobiology* 71: 5. https://doi.org/10.1007/500265-016-2239-3

Hubbard, K. A. & Chalfoun, A. D. 2012. An experimental evaluation of potential scavenger effects on snake road mortality detections. *Herpetological Conservation and Biology* 7 (2): 150-156.

Jochimsen, D. M., Peterson, C. R. & Harmon, L. J. 2014. Influence of ecology and landscape on snake road mortality in a sagebrush-steppe ecosystem. *Animal Conservation* Doi:10.1111/acv.12125

Jones, T. R., Babb, R. D., Hensley, F. R., LiWanPo, C. & Sullivan, B. K. 2011. Sonoran Desert snake communities at two sites: concordance and effects of increased road traffic. *Herpetological Conservation and Biology* 6 (1): 61-71.

Kioko, J., Kiffner, C., Jenkins, N. & Collinson, W. J. 2015. Wildlife roadkill patterns on a major highway in northern Tanzania. *African Zoology* 50 (1): 17-22. http://dx.doi.org/10.1080/15627020.2015.1021161

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

Quintero-Angel, A., Osorio-Dominguez, D., Vargas-Salinas, F. & Saavedra-Rodriguez, C. A. 2012. Road kill rate of snakes in a disturbed landscape of Central Andes of Columbia. *Herpetology Notes* 5: 99-105.

Reading, C.J., Luiselli, L.M., Akani, G.C., Bonnet, X. Amori, G., Ballouard, J.M., Filippi, E., Naulleau, G., Pearson, D. & Rugiero, L. 2010. Are snake populations in widespread decline? Biology Letters 6: 777-780. DOI: 10.1098/rsbl.2010.0373

Roe, J. H., Gibson, J. & Kingsbury, B. A. 2006. Beyond the wetland border: estimating the impact of roads for two species of water snakes. *Biological Conservation* 130: 161-168. Doi:10.1016/j.biocon.2005.12.010

Rosen, P. C. & Lowe, C. H. 1994. Highway mortality of snakes in the Sonoran Desert of Southern Arizona. *Biological Conservation* 68: 143-148.

Row, J. R., Blouin-Demers, G. & Weatherhead, P. J. 2007. Demographic effects of road mortality in black ratsnakes (*Elaphe obsoleta*). *Biological Conservation* 137: 117-124. Doi:10.1016/j.biocon.2007.01.020

Santhoshkumar, P. & Kannan, P. 2017. Impacts of roads on the mortality of endemic striped narrow headed snake *Xylophis perroteti* (Family: Xenodermatidae) in Nilgiris, Tamil Nadu. *Russian Journal of Herpetology* 24 (2): 87-90.

Schmidt, W. R. & Olsen, P. 1999. Using the road as a means of conducting herpetological surveys: an example from Warmbaths. African Herp News 28: 24-26.

van der Grift, E. A., van der Ree, R., Fahrig, L., Findlay, S., Houlahan, J., Jaeger, J. A. G., Klar, N., Madrinan, L. F. & Olson. L. 2013. Evaluating the effectiveness of road mitigation measures. *Biodiversity Conservation* 22: 425-448. Doi:10.1007/s10531-012-0421-0

Supplementary Figure 3S.1: R516 road in Limpopo Province.

Supplementary Figure 3S.2: Variety of road-killed snakes found on the road on Monday 9 October 1995.

CHAPTER 4

Changing landscape – the herpetofauna of a former grassland habitat, with reference to snake diversity and adaptability to urban transformation

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Formatted as a manuscript for submission to an international peer review journal

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Running header: Herpetofauna of a former grassland habitat

4.1 ABSTRACT

Urban development and the resultant transformation of habitat is a primary driver of local extinction for many species of fauna and flora. Grasslands are overlooked, yet species rich biomes that are often climatically suitable to agriculture, and where rich mineral deposits occur, are subject to industrial and urban development. Compared with forests and some other biomes, grasslands are often neglected in conservation planning strategies, yet play an important role

as hydrological catchment areas, as many grasslands are situated in regions subject to high rainfall. In South Africa, eastern escarpment has often been highlighted in many reports regarding its hydrological importance. Long-term site monitoring and historical species composition is often cited in biodiversity conservation textbooks as being a critical component in biodiversity conservation. Species inventories assist in conservation planning and ecological modelling, but often baseline data are unavailable to conservation planners and ecologists and the biological diversity of certain biomes is then not fully appreciated. In terms of biodiversity conservation, grasslands must be equally included in conservation strategies and planning and given as much attention as forests, savanna and other regional biomes. This study examined the herpetofaunal composition of a former grassland site which is now fully developed and highlights the exceptional diversity which declined because of anthropogenic development.

Key words: Grassland conservation; urban development; herpetofauna community; snake population declines.

4.2 INTRODUCTION

In southern Africa grasslands are often overlooked, yet species rich biomes which are under substantial threat from agriculture and urban/industrial development (Cilliers et al., 2004; Neke & Du Plessis, 2004; Bond & Parr, 2010). They are often situated in soil rich and climatically suitable regions ideal for crop production such as maize (*Zea mays*) and sunflowers (*Helianthus annuus*). The Grassland Biome is found chiefly on the high central plateau of South Africa, and the inland areas of KwaZuluNatal and the Eastern Cape (Mucina & Rutherford, 2006). The city of Johannesburg, South Africa, was founded in the centre of this, on the foundation of a massive gold reef and these rich mineral deposits led to rapid and vast urban transformation of the area (Appelgryn, 1984). This in turn stimulated industrial development, and a reliable water

supply from nearby aquatic systems such as the Vaal River, has ensured rapid economic expansion and development (Appelgryn, 1984). In addition, vast coal reserves situated nearby have allowed for steady power generation, further stimulating economic development and its associated influx of labour into the expanding urban landscape (Milstein, 1982; Appelgryn, 1984). This rapid growth led to increased pressure on natural ecosystems. The influx of people and associated anthropogenic changes have also resulted in introduced invasive alien species that have had a detrimental impact on water security and ecosystem services (Richardson & van Wilgen, 2004). Grasslands are often situated in important catchment areas. To make way for urban and agricultural developments, wetlands are often drained or altered to the detriment of aquatic species or those dependant on such habitats for foraging and refuge (Ellery et al., 2010).

In terms of conservation priority and ecosystem services, grasslands in South Africa have received relatively little attention compared with the savanna and fynbos biomes yet are equally important in terms of biodiversity, species richness and endemicity (Mucina & Rutherford, 2006). This can be attributable to the dearth of ecological studies compared with that of the savanna and fynbos biomes for example. However, the value of grasslands as important catchments and biological diversity hotspots is changing. Across the spectrum, species declines have been recorded in all animal classes including mammals (Ceballos & Ehrlich, 2002), birds (Donald et al., 2000; Both et al., 2006), amphibians (Beebee, 1992; Blaustein et al., 1994) and reptiles (Gibbons et al., 2000), including snakes (Reading et al., 2013). As an example, a flagship grassland reptile in South Africa, the sungazer or giant dragon lizard (*Smaug giganteus*), is a grassland endemic listed as Vulnerable because of agricultural pressure on its environment (Bates et al., 2014). Detailed studies on the impact of urban development on reptiles and amphibians are largely lacking for southern Africa and based primarily on anecdotal observations.

This study detailed observations on amphibian and reptile species taken over a 30-year period from 1988 to 2018 in three defined survey sites. It included further records from the greater eighth degree grid cell 2628AA/2, which is situated north-east of Johannesburg in Gauteng Province, South Africa, and specifically examined snake diversity and adaptability to peri-urban transformation. This study aimed to quantify the direct impact of anthropogenic development on grassland herpetofauna, particularly snakes. To our knowledge, this is the longest running, consistent, area specific, herpetological survey in South Africa. The primary objective of this study was to examine snake diversity, population density and individual species adaptability to an anthropogenic changing landscape. However, a broader ecological summary is provided to facilitate better understanding of ecological succession and urban development within the study area, and therefore a brief discussion of mammal, bird, amphibian and other reptile observations are also provided

4.3 METHODS

Informal and random herpetological surveys began around 1988 with more objective record-keeping initiated between 1992 to 2018. These entailed active searching for amphibians and reptiles by sight and recording observations in notebooks, diaries and journals. Individual species were also recorded in logbooks and allocated a field reference number, irrespective of whether the species was collected and donated to a natural history museum. Records, therefore, included a combination of visual, photographic and preserved voucher specimens. Due to pending housing developments in the survey sites, several voucher specimens were collected and accessioned into the Ditsong Museum of Natural History (Pretoria) and the National Museum (Bloemfontein) as referable records of occurrence. Searches included daylight searches for reptiles by lifting rocks, building rubble and garden refuse and where development was imminent, by opening moribund termitaria. Amphibians were recorded during night

searches by torchlight, however, numerous frogs were also found under rocks, building rubble, in waterside vegetation and openly exposed during daylight hours as in the case of giant bullfrogs (*Pyxicephalus adspersus)*.

A dataset totalling 350 records is included in this study, however, this is certainly an under-estimate of actual individuals observed, as many frog and lizard observations irrespective of densities, were taken as one record. For example, early records for Cape skinks (*Trachylepis capensis*) may have included an observation of several individual skinks on any given day but recorded in the journal entry as one record. All snake records after 1 January 1992 are of individual snakes. Observed population densities for frogs and lizards are explained in detail in the individual species accounts in Table 4S.1.

Three defined survey sites were regularly visited over varying periods of time and these are named Survey Sites A, B and C (Figures 4.1 and 4.2). In Table 4S.1, all records found outside these three survey sites are listed as Site 'X'. These are of records plotted throughout eighth degree grid cell 2628AA/2 with numerous records coming from urban or industrial areas (see species maps below). They are included to give greater spatial analyses of species occurrence in the general area.

At least 25-30 individual excursions to Site A took place between 1988 and 2018; approximately ten excursions to Site B and 15-20 excursions to Site C. Records from Site 'X' were completely random, except for at least 2-3 excursions to an area west of Site A (Chloorkop/Midrand area) in the early 1990s, which was also subsequently developed. No excursions took place between 1 March 1997 and 31 March 1999 when the senior author was based at Kwena Gardens, Sun City. Only two or three short visits took place after 2011, as much of the area had undergone development, and remaining pockets of grassland was generally inaccessible.

All locality coordinates were entered into the global information systems (GIS) Software Package QGIS (https://www.qgis.org) to generate species distribution maps for the area. To document snake species diversity within the study site, all mapped records from adjacent quarter degree grid cells were included (taken from Bates et al., 2014). These are summarised in Table 4S.2. Simple descriptive statistics and correlations were conducted with Statistica (Statsoft, Tulsa, OK).

The survey sites are situated in an area to the north of Kempton Park on the border with Tembisa and adjacent to the suburbs of Birch Acres, Norkem Park and Birchleigh North, Gauteng Province. WRS moved to a recently built house in Birch Acres during March 1975 at the age of 20 months. Although formal herpetological documentation began after 1988, at least two prior observation events are recorded. In 1975, the surrounding area near the house was open grassland (veld). In 1978, a sub-adult aurora snake (*Lamprophis aurora*) was killed on the property during building construction. In the same year, a large giant bullfrog (*Pyxicephalus adspersus*) was removed from a water-logged ditch dug for drainage pipes and relocated into adjacent grassland. However, herpetological surveys began in 1988 coinciding with a developing interest in herpetology.

Kempton Park currently forms a town within the greater municipality of Ekurhuleni (formerly the East Rand) in Gauteng Province, South Africa. Historically, it comprised of two Boer farms – Zuurfontein No 369 with the deed issued to a Johannes Stephanus Marais on 25 October 1859, and another portion called Rietfontein 32 registered to a Cornelius Johannes Beukes in March 1865. Gold was discovered in Johannesburg in 1886, approximately 22 km southwest of the farms. The first major industrial development was in the form of the *Zuid Afrikaansche Fabrieken voor Ontplofbare Stoffen*, a dynamite-producing factory built to supply the mines. A railway line passed through the region connecting Pretoria to Vereeniging, with an additional line constructed to accommodate the new dynamite factory, later called the

AECI. Kempton Park was formally established on 24 August 1903 when Karl Friedrich Wolff subdivided a portion of Zuurfontein farm into 216 residential stands. The influx of workers to the dynamite factory and associated industrial developments lead to a rapid increase in urban housing and other commercial and recreational developments. Johannesburg International Airport (previously called Jan Smuts Airport) was developed in 1952 and opened in 1953. (Historical data obtained from https://www.kemptalk.com/history_of_kempton_park.htm .

The suburbs of Birch Acres, Norkem Park and Birchleigh North, which encompassed the survey sites, were developed in the early 1970s, with development continuing sporadically through to 2018. Historically, prior to 1900, the Kempton Park region would have seen permanent or migratory larger grassland mammals including aardwolf (*Proteles cristatus*); brown hyena (*Parahyaena brunnea*); cheetah (*Acionyx jubatus*); lion (*Panthera leo*); white rhinoceros (*Ceratotherium simum*); plains zebra (*Equus quagga*); hippopotamus (*Hippopotamus amphibious*); eland (*Tragelaphus oryx*); black wildebeest (*Connochaetes gnou*); red hartebeest (*Alcelaphus buselaphus*); blesbok (*Damaliscus pygargus phillipsi*) and waterbuck (*Kobus ellipsiprymnus*). A lion was reportedly captured in recent times (no date given) near Heidelberg, Gauteng (Skinner & Chimimba, 2005). See also Boshoff et al. (2015) for further details on historical mammal distributions. For further historical insight into the region and northern Johannesburg, see Milstein (1982). Some of these mammals can only now be observed in the Rietvlei Nature Reserve situated 18 km north-east of the survey sites.

4.3.3 Description of survey sites

4.3.3.1 Eighth degree grid cell 2628AA/2

The eighth-degree grid cell 2628AA/2 includes a surface area of approximately 17 380 ha and situated north-east of the City of Johannesburg, Gauteng Province, South Africa (Figure 4.1). It encapsulates the area south of latitude 26°00'00"S and north of latitude 26°07'30"S and east

of longitude 28°07'30"E and west of longitude 28°15'00"E. The north-western corner fits into Halfway House, Midrand and the north-eastern portion touches on the R21 freeway just east of Tembisa. The south-western corner includes Edenvale/Greenstone and OR Tambo International Airport makes up the south-eastern corner. At least 80% of the surface area comprises urban residential housing and industrial complexes, with the remaining <20% consisting of small-holdings and highly fragmented grassland. The Modderfontein Conservation Area (MCA) makes up a small portion in the central western part of this grid cell but is highly degraded and invaded by alien vegetation, therefore its conservation value is questionable. The surrounding area of the MCA is also under heavy developmental pressure and it is envisaged that virtually no open grassland will remain in this grid cell within the next decade. There are very few wetlands in the area, with several small ephemeral pans and perennial streams. These streams are often bordered by extensive stands of *Phragmites* reed-beds. The MCA has a few small man-made dams supporting introduced and indigenous fish such as carp (*Cyprinus carpio*) and sharp-tooth catfish (*Clarias gariepinus*) (WRS pers. obs.). African fish-eagles (*Haliaeetus vocifer*) are occasionally sighted and heard in the MCA. Altitudinal variation is between 1554 m to 1679 m a.s.l. The ground is mildly undulating with few scattered rocky outcrops. The rocky ridges of Linksfield and Fishers Hill/Primrose falls just south of this grid cell, therefore there are no prominent geological features within the study area.

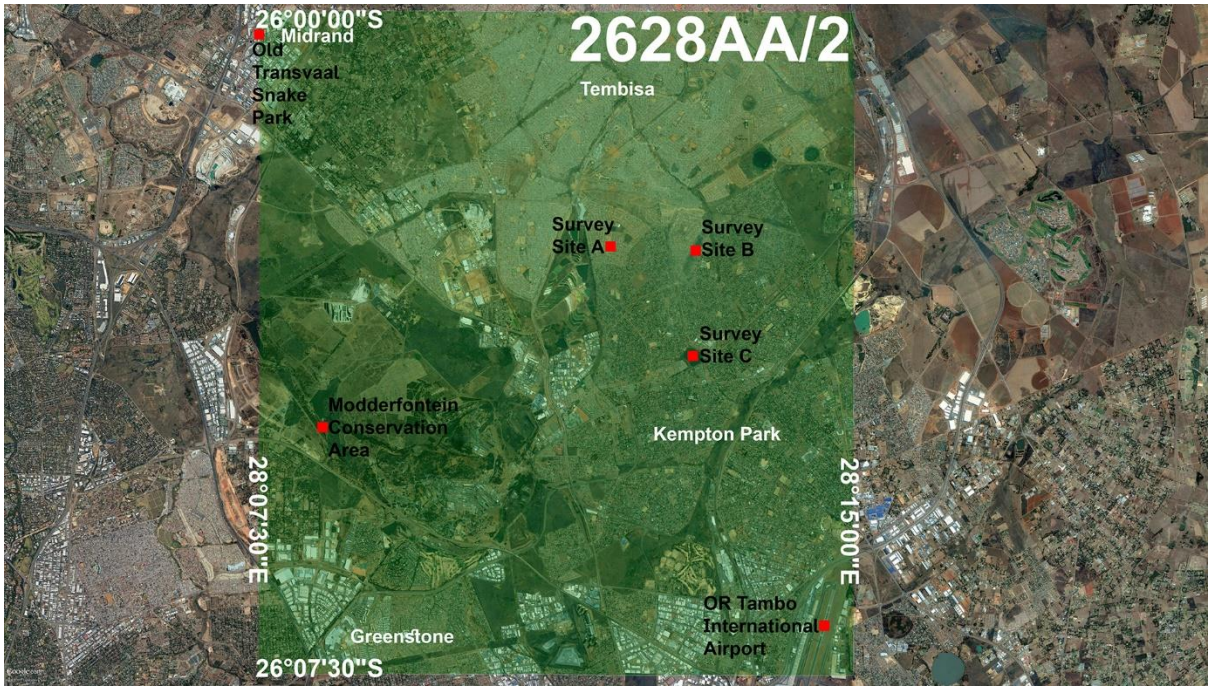


Figure 4.1: Google Earth image of the eighth-degree grid cell 2628AA/2 showing landmark features.

4.3.3.2 Vegetation type

The study area falls within the Grassland Biome and Mesic Highveld Grassland Bioregion (Mucina & Rutherford, 2006). The predominant natural vegetation type is Gm 10 – Egoli Granite Grassland, which included the three main survey sites. Just to the south and east, it is replaced by Carletonville Dolomite Grassland, but most of this is now developed (Mucina & Rutherford, 2006). Egoli Granite Grassland is listed as Endangered (Mucina & Rutherford, 2006) and further mass development within this grassland type (Midrand/Centurion) over the last decade has no doubt exasperated this assessment. Dominant grassland species include *Hyparrhenia hirta* with other graminoids, herbs and low shrubs. Winter fires are frequent. Few alien invasive plant species were recorded within the Survey Sites (see below), but some areas within 2628AA/2 are heavily invaded. In urban landscapes, pavements and parks, bugweed (*Solanum mauritianum*), tree-of-heaven (*Ailanthus altissima*), black locust (*Robinia pseudoacacia*) and moth catcher (*Araujia sericifera*) dominate. Australian black wattle (*Acacia*

mearnsii) appears relatively scarce compared with some grassland areas (WRS pers. obs.). Within the Modderfontein Conservation Area, vast swathes of pine (*Pinus* spp.); gums (*Eucalyptus* spp.) and poplar (*Populus* spp.) can be found. Exotic perennial and annual herbaceous plants noted in the MCA include blackjack (*Bidens pilosa*), spear thistle (*Cirsium vulgare*), cosmos (*Cosmos bipinnatus*), tall khaki weed (*Tagetes minuta*), spiny cocklebur (*Xanthium spinosum*) and large cocklebur (*Xanthium strumarium*).

4.3.3.3 Survey Site A

Survey Site A was the main area surveyed and had an area of ~212 ha (Figures 4.1 and 4.2). The area included open grassland with *Hyparrhenia hirta* as one of the dominant grass species. Some disturbed areas were taken over with patches of bankrupt bush (*Seriphium plumosum*). Various herbaceous annuals and perennials were observed but species not identified. A stand of several large *Eucalyptus* trees was positioned centrally within this grassland patch, with an adjacent patch of poplar (*Populus* spp.). This was a prime nesting spot for spotted grass snakes (*Psammophylax rhombeatus*) (see species account below). Apart from the *Eucalyptus* and *Populus*, the only other invasive alien plants noted occurred on disturbed soil on the periphery and included blackjack (*Bidens pilosa*), tall khaki weed (*Tagetes minuta*) and common thorn-apple (*Datura ferox*). Natural rock features were non-existent barring an embedded flat rock approximately 3 x 5 m in extent with a few eroded depressions which would hold rainwater for several days until evaporated. Numerous active and moribund termite mounds were scattered across the area. These termite mounds, produced by *Trinervitermes* sp., are extremely important refugia for a variety of invertebrates, arachnids, small mammals and reptiles. A pedestrian footpath ran diagonally between Birch Acres and Tembisa, but in later years several dirt tracks from motor vehicles appeared, which facilitated dumping of building rubble and garden refuse. Alongside the footpath, and in several random spots, dumped building rubble in

the form of concrete slabs, bricks, asbestos sheets, ornamental rocks, porcelain, rubber sheets and corrugated iron was present. Garden refuse in the form of organic plant materials (branches and leaves) was also dumped. Interestingly, the building rubble and garden refuse may have initially contributed to increased reptile species density and diversity prior to development and associated increased human activity (see discussion below). Low-cost housing developments started around 2000 and by 2012, 90% of Survey Site A had been developed (Figures 4S.1-5). During the intervening years, the area became progressively degraded with a lower density of grasses (Figures 4S.1-5). Winter fires were frequent (WRS pers. obs.). The first records were taken in 1988 and the last record (WRS R-00795) taken on 7 October 2011. The data set spanned a period of 23 years (Table 4S.2).

4.3.3.4 Survey Site B

Survey Site B had an area of ~122 ha and this area is adjacent to Pongola River Drive bordering the suburb of Norkem Park (Figures 4.1 and 4.2). A small perennial stream drains water from storm-water culverts forming the Kaalfontein stream further down. As with Site A, sporadic patches of building rubble and garden material were dumped, but not near as extensive. Several natural rocky outcrops occurred adjacent to the stream at the lower north-westerly end. Active and moribund termite mounds were common over most of the area away from the stream. Housing developments were underway by 1988 when exploration of this site commenced (Figures 4S.1-5). Invasive alien vegetation included a few common herbaceous weeds, but pompom weed (*Campuloclinium macrocephalum*) was first recorded at this survey site on 17 January 2013. There remains open but degraded grassland on either side of the stream, so it is possible that some reptiles are still to be found, but at least two recent visits in 2016 and 2017 failed to reveal any species.

The first record was taken in February 1991 (WRS (A) R-00072) and the last record on 7 September 1995 (WRS (A) R-00434). The data set spanned a period of only 4 years for this site, although two site visits were conducted in 2016 and 2017.

4.3.3.5 Survey Site C

Survey Site C had an area of ~32 ha, excluding the narrow Eskom servitude joining Site C with Site B. Site C included the Birch Acres pan which has an interesting hydrological history (Figures 4.1 and 4.2). Prior to 1990, this site was mostly a dry, sandy dustbowl used as a BMX track by schoolchildren (WRS pers. obs.). It was surrounded by open grassland with an Eskom servitude (high-tension power lines) running through the middle leading to Survey Site B. During the 1988/1989 summer, a period of heavy rainfall filled this depression with water to an average depth of 20 - 30cm. The surface area of water was approximately 10 ha with relatively little aquatic vegetation. This event was shortly followed by a mass emergence of adult giant bullfrogs (*Pyxicephalus adspersus*) which began breeding (see species account below). Interestingly, the pan has remained waterlogged since and has never dried up during the period 1989-2018 (WRS pers. obs.). Water depth and vegetational composition has varied over time. In one measurement taken by WRS, some areas of the pan exceeded 1 m in depth (mid 1990s). There appears to have been successive periods of water stagnation and varying degrees of emergent vegetation, mostly in the form of sedges, reeds and grasses. In 2018, the peripheral vegetation was almost impenetrable, blocking ease of access to the water. A water reservoir is present to the north-eastern section of the pan and in the early 1990s a refuse transfer station was built on the south-eastern quadrant. Adjacent to the eastern side of the pan was open grassland, but this was subsequently developed in the late 1980s into a shopping complex (Norkem Mall) and townhouses. Around 1995, a fast-food outlet and further townhouses were built adjacent to the pan, followed by further townhouse developments after

2000 on the western fringes. These developments effectively destroyed foraging habitat for *Pyxicephalus adspersus* and after 1995 a rapid decline in frogs was observed. The first records were taken in late 1988 and the last record taken on 10 May 2008 – a survey period spanning 20 years. However, quick visual site visits have continued up to and including 2018.

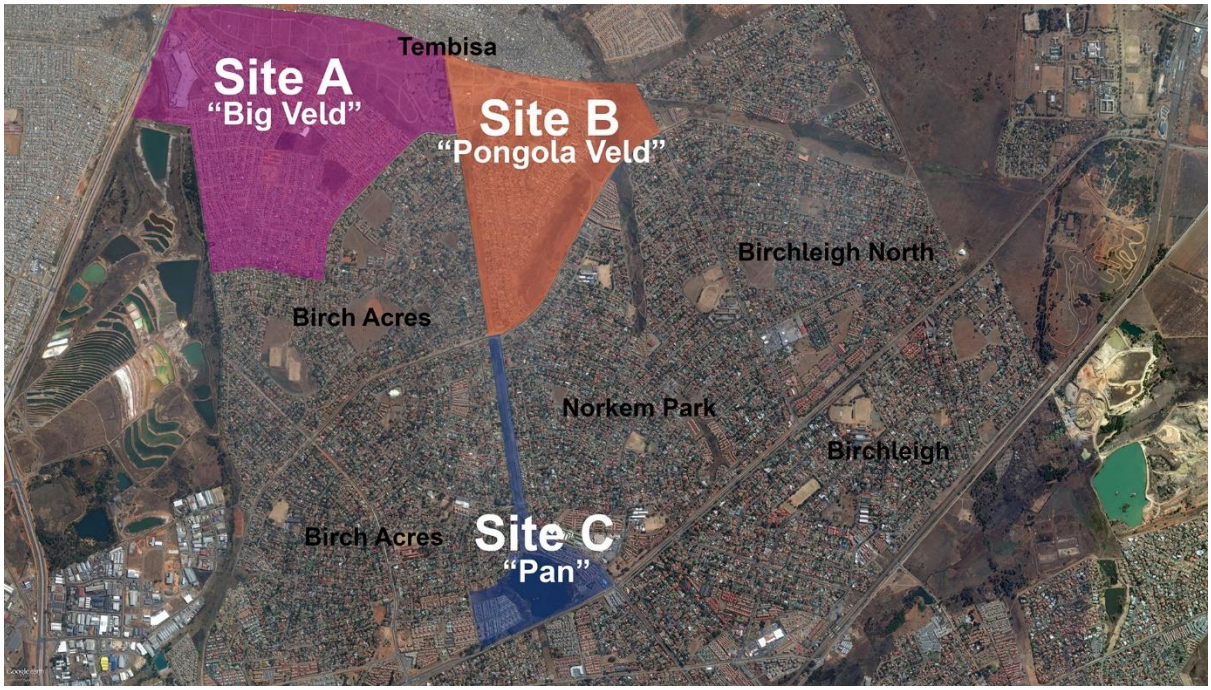


Figure 4.2: Satellite image showing the location of study sites A, B and C on the periphery of Birch Acres, Norkem Park and Birchleigh North in Kempton Park.

4.4 RESULTS

A total of 350 records were obtained during the surveys comprising ten amphibian species, one chelonian, 11 lizard species and 22 snake species (Summarised in Table S4.1 and Figure S4.5.) Potential snake diversity for the eighth-degree grid cell under review was determined by examining available records from quarter degree grid cell 2628AA and all adjacent grid cells (Table S4.2). Data were extracted from Bates et al. (2014).

A total of 195 records were taken at Survey Site A including one frog, 56 lizard and 138 snake records. A total of 22 records were taken at Survey Site B including three frog, six

lizard, 12 snake and one terrapin record. The relatively small number of records here was a result of limited sampling due to increased human presence and housing developments. A total of 31 records were taken at Survey Site C including 21 frog, three lizard and seven snake records.

A total of 44 taxa were identified representing 33.6% of South Africa's species diversity. However, 17 species are savanna specialists which infiltrate the northern grid cells and therefore can be excluded from this analysis. Therefore, 27 species can be expected to occur within the Survey Sites. In addition, six exotic escapees were caught by WRS from urban areas, including *Python bivittatus*, *Lampropeltis californiae*, *Lampropeltis triangulum sinaloae*, *Orthriophis taeniurus friesei*, *Pantherophis alleghaniensis*, *P. guttatus* and *P. obsoletus*. These species were excluded from the analysis but are briefly highlighted under the discussion below.

The records of snouted cobras (*Naja annulifera*) and southern African python (*Python natalensis*), both savanna species, were also excluded, as these are undoubtedly accidental translocations. However, snouted cobras, Mozambique spitting cobras (*Naja mossambica*), black mambas (*Dendroaspis polylepis*) and boomslang (*Dispholidus typus viridis*) were frequently captured in and around Johannesburg. The majority of these were accidental translocations, but with climate change, these records should be logged and monitored, as it is believed natural breeding populations of *N. annulifera* and *N. mossambica* occur in predominantly grassland areas such as Fourways, Diepsloot, Kyalami and some parts of north-western Midrand (pers. obs. and communications with various snake catchers).

Of the 27 species expected within the Survey Sites, 17 species were definitively recorded (Table 4S.2). The absence of ten species may be attributable to lack of suitable rocky habitat, (i.e. *Prosymna sundevallii*, *Psammophylax tritaeniatus*, *Bitis arietans*), or gaps in sampling effort and detection (i.e. *Atractaspis bibronii*; *Psammophis brevirostris*), or possible

extirpation from the area due to habitat transformation (i.e. *Homoroselaps dorsalis*, *H. lacteus*, *Psammophis trinasalis*).

Snakes – Population density, declines and adaptability

A total of 15 species totalling 206 individual snake records were analysed. Nine species were predominately nocturnal while six species were diurnal. Of the snake species recorded, 12 were oviparous while three species give birth to live young. Of the 15 species, seven can be considered as specialist feeders. Five of these appear unable to adapt to urban transformation and only the two frog specialists, *Causus rhombeatus* and *Crotaphopeltis hotamboeia* are known to infiltrate urban landscapes that border wetlands or drainage lines (WRS pers. obs.). *Afrotyphlops bibronii*, *Aparallactus capensis*, *Lycophidion capense* and *Dasypeltis scabra*, although generally common in grasslands, appear vulnerable to urban development. Generalists that appear vulnerable and unable to adapt to transformation include the small elapid *Elapsoidea sundevallii media* and the large lamprophiid *Pseudaspis cana*. Although *Pseudaspis cana* are occasionally removed from peri-urban or urban properties, these are usually on the border of more extensive open grasslands and populations appear to be declining in areas of high disturbance and development (WRS pers. obs.). The water snake *Lycodonomorphus rufulus* can be locally abundant in wetlands but population density appeared strongly correlated with amphibian prey availability and wetland quality. They were relatively common at Survey Site C, but practically vanished in later years as the environmental quality of the pan deteriorated and frog numbers declined (WRS pers. obs.).

4.5 DISCUSSION

Globally reptilian, and especially snake populations, are acknowledged to be in decline (Gibbons et al., 2000; Reading et al., 2010). Anthropogenic habitat destruction is cited as one

of the most important drivers of species extinction in the world (Pimm & Raven, 2000). In South Africa, a relatively small percentage of grasslands fall within protected areas (less than 3%) (Low & Rebelo, 1996.) It is estimated that at least 30% of grasslands have been permanently transformed, with at least 23% of this attributed to agriculture (Fairbanks et al., 2000). However, this figure is likely substantially higher because of urban development in the intervening 18 years, especially in central Gauteng. Climate change is predicted to threaten this biome even further with estimates of up to 55% (Mucina & Rutherford, 2006).

A study by Masterson et al. (2009) examined the herpetofauna in pristine and disturbed grassland in Suikerbosrand Nature Reserve, Gauteng Province, South Africa. In this study using trap arrays, a total of 119 snakes comprising 14 species were captured. Of these species, 12 were also recorded in the study sites in the present study, therefore allowing comparison. Two species that were absent from Kempton Park in the present study but recorded in the Suikerbosrand study included the puff adder and Bibron's stiletto snake *Atractaspis bibronii*. The puff adder was absent from Kempton Park most likely due to the absence of suitable rocky terrain (WRS pers. obs.). *Atractaspis bibronii* is likely to occur in Kempton Park but was not found. The study of Masterson et al. (2009) clearly demonstrated that snake densities were proportionally much higher in pristine grassland than in formerly disturbed (previously agricultural) grassland. This is interesting in that observations from Kempton Park have indicated that the dumping of building rubble and garden refuse may have increased population densities of some snake species by providing suitable refugia for shelter, as well as providing suitable nesting sites (WRS pers. obs.). Most notably, *Psammophylax rhombeatus* utilised pre-cast concrete wall slabs as nesting sites and *Lamprophis aurora* was commonly found in building rubble such as brick piles etc. Lizards, including geckos, were commonly found under building rubble and may have provided ideal hunting grounds for *Lycophidion capense*. Surprisingly, the brown house snake *Boaedon capensis* was not nearly as common as

Lamprophis aurora despite often being cited as one of the snakes most commonly found in urban landscapes.

4.5.1 Landscape change and decline in snakes

Although the study sites were historically degraded by grazing and other agricultural practices, pockets of pristine grassland remained in numerous sites in Kempton Park in the 1970s and 1980s. Increased urban development during the late 1980s and early 1990s coincided with increased dumping of building rubble into these open grassland pockets, which initially appeared to favour certain snake species. Increased human activity and disturbance was however detrimental to several mammal and bird species such as common duiker and grass and marsh owls and even common hedgehogs which had disappeared from the area by the mid-1990s. However, after 2000, rapid urban development destroyed much of the remaining grasslands leading to local extirpation of most snake and reptile species, as subsequent surveys into the few remaining pockets of grassland failed to reveal further species. Interestingly, most of the latter records include species such as *Lygodactylus capensis*, *Trachylepis punctatissima* and *Hemidactylus mabouia*, all species which are highly commensal and thrive in urban gardens and homes. It comes as no surprise that the last four snakes recorded happened to be escaped pets found roaming in urban gardens. These included a Burmese python *Python bivittatus* and three North American rat snakes: *Pantheropis guttatus*, *P. alleghaniensis* and *P. obsoletus*.

Grasslands are important biomes in terms of hydrological and ecosystem services. They are also species rich biomes with high levels of endemicity. 67% of orchids occur in the grassland biome in South Africa (Linder et al., 2005) and at least 34 grass taxa are endemic to the biome (Mucina & Rutherford, 2006). Several Critically Endangered bird species occur and breed exclusively in the grassland biome, including wattled cranes *Bugeranus carinculatus* and

blue swallow *Hirundo atrocaerulea* (Taylor et al., 2015). Habitat loss, fragmentation and degradation was determined to be the single greatest threat to reptiles in South Africa with almost 50 taxa being directly affected by agriculture and infrastructure development (Bates et al., 2014).

This study detailed one of the longest running herpetological site-specific surveys undertaken in South Africa, highlighting the rich herpetological diversity that can be found in even relatively small grassland fragments. On a larger spatial scale, urban development has undoubtedly had a detrimental impact on amphibians and reptiles, but because of the lack of data, the impacts are largely overlooked or dismissed. For example, a search on the Reptile Atlas of Southern Africa online virtual museum database (www.vmus.adu.org.za) for quarter degree grid cell 2628AA, only shows 60 records taken over 16 years between 2002 and 2018 (accessed on 1/12/2018). Of these, only 12 are of snakes. This study includes 330 records from the eighth-degree grid cell 2628AA/2 and the dataset currently holds 231snake records of 26 different species (Table 4S.2). The paucity of protected areas within the grassland biome is cause for concern and further pressure on politicians and government to declare more nature reserves in this biome is of paramount importance, considering its strategic importance in ecosystem services and biological diversity.

4.6 ACKNOWLEDGEMENTS

We are grateful to the University of KwaZulu-Natal and the National Research Foundation (ZA) for funding CTD.

4.7 REFERENCES

Appelgryn, M. S. 1984. Johannesburg: origins and early management, 1886-1899. UNISA, Pretoria.

Bates, M. F. 1990. Where do egg-eaters find food in open grasslands? African Herp News 13: 21-23.

Bates, M. F. & Little, I. T. 2013. Predation on the eggs of ground-nesting birds by *Dasypeltis scabra* (Linnaeus, 1758) in the moist grasslands of South Africa. African Journal of Herpetology 62 (2): 125-134.

Bates, M. F., Branch, W. R., Bauer, A. M., Burger, M., Marais, J., Alexander, G. J., & De Villiers, M. S. (eds). 2014. Atlas and Red List of the Reptiles of South Africa, Lesotho & Swaziland. *Suricata* 1. South African National Biodiversity Institute, Pretoria.

Bond, W. J. & Parr, C. L. 2010. Beyond the forest edge: Ecology, diversity and conservation of the grassy biomes. Biological Conservation 143 (10): 2395-2404. https://doi.org/10.1016/j.biocon.2009.12.012

Boshoff, A., Landman, M. & Kerley, G. 2015. Filling the gaps on maps: historical distribution patterns of some larger mammals in parts of southern Africa. Transactions of the Royal Society of South Africa. http://dx.doi.org/10.1080/0035919X.2015.1084066

Both, C., Bouwhuis, S., Lessells, C. M. & Visser, M. E. (2006). Climate change and population declines in a long-distance migratory bird. *Nature* 441. Doi:10.1038/nature04539

Branch, W. R. 1998. Field guide to snakes and other reptiles of southern Africa. 399pp. Struik Publishers, Cape Town.

Ceballos, G. & Ehrlich, P. R. 2002. Mammal population losses and the extinction crisis. Science 296: 904-907.

Cilliers, S.S., Müller, N. & Drewes, E. 2004. Overview on urban nature conservation: situation in the western-grassland biome of South Africa. *Urban Forestry and Urban Greening* 3(1): 49-62. https://doi.org/10.1016/j.ufug.2004.04.003

Donald, P. F., Green, R. E. & Heath, M. F. 2000. Agricultural intensification and the collapse of Europe's farmland bird populations. *Proceedings of the Royal Society, London B* (2001) 268: 25-29. Doi:10.1098/rspb.2000.1325

Ellery, W., Grenfell, S. & Kotze, D. 2010. A method for assessing cumulative impacts on wetland functions at the catchment or landscape scale. Unpublished report, Water Research Commission, Pretoria.

Fairbanks, D. H. K., Thompson, M. W., Vink, D. E. Newby, T. S., Van Den Berg, H. M. & Everard, D. A. 2000. The South African land-cover characteristics database: a synopsis of the landscape. *South African Journal of Science* 96: 69-82.

Gibbons, J. W., Scott, D. E., Ryan, T. J., Buhlman, K. A., Tuberville, T. D., Metts, B. D., Greene, J. L., Mills, T., Leiden, Y., Poppy, S. & Winne, C. T. 2000. The global decline of reptiles, déjà vu amphibians. BioScience 50 (8): 653-666.

Griffiths, C., Day, J. & Picker, M. 2015. Freshwater Life – A field guide to the plants and animals of southern Africa. Struik Nature.

Hockey, P. A. R., Dean, W. R. J. & Ryan, P. G. (eds). 2005. Roberts – Birds of Southern Africa, VIIth ed. The Trustees of the John Voelcker Bird Book Fund, Cape Town.

Light, J. L. 2015. The distribution and urban occurrence of the elusive southern African hedgehog (*Atelerix frontalis*). MSc Dissertation, University of the Witwatersrand.

Linder, H. P., Kurzweil, H. & Johnson, S. D. 2005. The southern African orchid flora: composition, sources and endemism. *Journal of Biogeography* 32: 29-47.

Masterson, G. P. R., Maritz, B., Mackay, D. & Alexander, G. J. 2009. The impacts of past cultivation on the reptiles in a South African grassland. African Journal of Herpetology 58 (2): 71-84.

Milstein, P. le S. 1982. The highveld before civilization. The Sandton Field Book. Edited by Vincent Carruthers and published by the Sandton Nature Conservation Society.

Mucina, L. & Rutherford, M. C. (eds) 2006. The vegetation of South Africa, Lesotho & Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Neke, K. & Du Plessis, M. A. 2004. The threat of transformation: quantifying the vulnerability of grasslands in South Africa. Conservation Biology 18(2): 466-477.10.1111/j.1523-1739.2004.00157.x

Norval, G. & Norval, A. W. 2007. A description of opportunistic foraging behaviour in the dotted skink *Trachylepis punctatissima* (Smith, 1849), in an urban setting. Sauria 29 (2): 44-47.

Pimm, S. L. & Raven, P. 2000. Biodiversity: extinction by numbers. *Nature* 403: 843-845.

Reading, C. J., Luiselli, L. M., Akani, G. C., Bonnet, X., Amori, G. Ballouard, J. M., Filippi, E., Naulleau, G., Pearson, D. & Rugiero, L. 2010. Are snake populations in widespread decline? Biology Letters 6: 777-780.

Richardson, D. M. & van Wilgen, B. W. 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? South African Journal of Science 100: 45-52.

Schmidt, W. R. 1999. Natural History Notes: *Dasypeltis scabra* – Colouration. African Herp News 29: 40.

Skinner, J. D. & Chimimba, C. T. 2005. The Mammals of the Southern African Subregion (Third Edition). Cambridge University Press.

Sodhi, N. S. & Ehrlich, P. R. (eds). 2010. Conservation Biology for All. Oxford University Press. 339pp.

Taylor, M. R., Peacock, F. & Wanless, R. M. (eds). 2015. The 2015 Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland. Birdlife South Africa, Johannesburg, South Africa.

Thomas, R. L., Owen-Smith, L., Drake, D. C. & Alexander, G. J. 2014. Restoring breeding habitat for giant bullfrogs (*Pyxicephalus adspersus*) in South Africa. African Journal of Herpetology 63 (1): 13-24.

Yetman, C. A & Ferguson, J. W. H. 2011. Spawning and non-breeding activity of adult giant bullfrogs (*Pyxicephalus adspersus*). African Journal of Herpetology 60 (1): 13-29.

Supplementary Table S4.1: Records of amphibians and reptiles recorded from the Eighth Degree Grid Cell 2628AA/2. This table includes 350 records detailing the Survey Sites. Site X indicates records that were outside of the three main Survey Sites A, B and C. Record type includes either Preserved Museum Voucher, Photographic or Sight. All museum vouchers are accessioned in the Ditsong Museum of Natural History (Pretoria) and the National Museum (Bloemfontein).

Reference Number:	Species:	Date:	Survey Site:	Record Type:
Class Amphibia Order Anura				
Archaeobatrachia Family: Pipidae				
WRS (A) A-00002	*Xenopus laevis*	00/00/1990	C	Sight
WRS (A) A-00018	*Xenopus laevis*	20/03/1992	C	Sight
WRS A-00104	*Xenopus laevis*	28/04/2006	X	Photographic
Neobatrachia Family: Bufonidae				
WRS A-00042	*Schismaderma carens*	11/10/2003	X	Photographic
WRS A-00092 Pending NM	*Schismaderma carens*	03/12/2005	X	P Voucher
WRS A-00098 Pending NM	*Schismaderma carens*	11/12/2005	X	P Voucher
WRS (A) A-00003	*Sclerophrys gutturalis*	00/00/1990	C	Sight
WRS (A) A-00083	*Sclerophrys gutturalis*	17/09/1995	C	Calls
WRS A-00040	*Sclerophrys gutturalis*	22/02/2003	C	Photographic
WRS A-00043	*Sclerophrys gutturalis*	11/10/2003	X	Photographic
Family: Hyperoliidae				
WRS (A) A-00010	*Kassina senegalensis*	00/00/1990	C	Sight
WRS (A) A-00017	*Kassina senegalensis*	19/01/1992	C	Sight
WRS (A) A-00019	*Kassina senegalensis*	20/03/1992	C	Sight
WRS (A) A-00054 TM79603	*Kassina senegalensis*	06/04/1994	C	P Voucher
WRS A-00091	*Kassina senegalensis*	08/01/2005	C	Calls heard
Family: Phrynobatrachidae				
WRS (A) A-00005	*Phrynobatrachus natalensis*	00/00/1990	B	Sight
Family: Pyxicephalidae – Cacosterninae				
WRS (A) A-00007	*Amietia delalandii*	00/00/1990	C	Sight
WRS (A) A-00021	*Amietia delalandii*	20/03/1992	C	Sight
WRS (A) A-00004	*Cacosternum boettgeri*	00/00/1990	C	Sight
WRS (A) A-00130	*Cacosternum boettgeri*	23/07/1996	C	Sight
WRS A-00054	*Cacosternum boettgeri*	28/10/2003	C	Calls heard
WRS A-00082	*Cacosternum boettgeri*	14/11/2004	C	Calls heard
WRS A-00083	*Cacosternum boettgeri*	14/11/2004	X	Calls heard
WRS A-00199	*Cacosternum boettgeri*	00/01/2009	X	Calls heard
WRS (A) A-00008	*Tomopterna cryptotis*	00/00/1990	B	Sight
WRS A-00063	*Tomopterna cryptotis*	27/11/2003	X	Calls heard
WRS (A) A-00009	*Tomoptrna natalensis*	00/00/1990	B	Sight
Family: Pyxicephaliidae – Pyxicephalinae				
WRS (A) A-00001	*Pyxicephalus adspersus*	00/00/1978	X	Sight
WRS (A) A-00006	*Pyxicephalus adspersus*	00/00/1990	C	Sight
WRS (A) A-00016	*Pyxicephalus adspersus*	19/01/1992	C	Sight
WRS (A) A-00020	*Pyxicephalus adspersus*	20/03/1992	C	Sight
WRS A-00051	*Pyxicephalus adspersus*	22/10/2003	X	Photographic
WRS A-00052	*Pyxicephalus adspersus*	26/10/2003	X	Photographic
WRS A-00087	*Pyxicephalus adspersus*	26/12/2004	A	Photographic
WRS A-00090	*Pyxicephalus adspersus*	08/01/2005	C	Photographic

WRS A-00186	*Pyxicephalus adspersus*	10/05/2008	C	Sight
Class: Reptilia				
Order: Testudinata Suborder: Cryptodira				
Family: Pelomedusidae				
WRS (A) R-00042	*Pelomedusa galeata*	00/00/1990	B	Sight
Order: Squamata – Sauria				
Family: Gekkonidae				
WRS R-00853	*Hemidactylus mabouia*	10/07/2012	X	Photographic
WRS (A) R-00115	*Lygodactylus capensis*	18/01/1992	X	Sight
WRS R-00147	*Lygodactylus capensis*	31/08/2002	X	Sight
WRS R-00164	*Lygodactylus capensis*	22/02/2003	A	Photographic
WRS R-00260	*Lygodactylus capensis*	17/04/2004	X	Photographic
WRS R-00261 Pending NM	*Lygodactylus capensis*	29/04/2004	X	P Voucher
WRS R-00265 Pending NM	*Lygodactylus capensis*	30/09/2004	A	P Voucher
WRS R-00266 Pending NM	*Lygodactylus capensis*	30/09/2004	A	P Voucher
WRS R-00279 Pending NM	*Lygodactylus capensis*	30/09/2004	A	P Voucher
WRS R-00359	*Lygodactylus capensis*	26/11/2005	X	Sight
WRS R-00376	*Lygodactylus capensis*	18/12/2005	X	Sight
WRS R-00454	*Lygodactylus capensis*	13/01/2007	X	Sight
WRS R-00465	*Lygodactylus capensis*	02/02/2007	X	Sight
WRS R-00543	*Lygodactylus capensis*	29/09/2007	X	Sight
WRS R-00598 SARCA#004386	*Lygodactylus capensis*	12/01/2008	X	Photographic
WRS (A) R-00435	*Pachydactylus affinis*	07/09/1995	B	Photographic
WRS (A) R-00622	*Pachydactylus affinis*	23/07/1996	A	Sight
WRS (A) R-00623	*Pachydactylus affinis*	23/07/1996	A	Sight
WRS (A) R-00624	*Pachydactylus affinis*	23/07/1996	A	Sight
WRS R-00031 TM83460	*Pachydactylus affinis*	18/06/2000	A	P Voucher
WRS R-00127	*Pachydactylus affinis*	06/07/2002	A	Sight
WRS R-00129 TM85047	*Pachydactylus affinis*	06/07/2002	A	P Voucher
WRS R-00142	*Pachydactylus affinis*	31/08/2002	A	Sight
WRS R-00165	*Pachydactylus affinis*	22/02/2003	A	Sight
WRS R-00268 Pending NM	*Pachydactylus affinis*	30/09/2004	A	P Voucher
WRS R-00269 Pending NM	*Pachydactylus affinis*	30/09/2004	A	P Voucher
WRS R-00270 Pending NM	*Pachydactylus affinis*	30/09/2004	A	P Voucher
WRS R-00271 Pending NM	*Pachydactylus affinis*	30/09/2004	A	P Voucher
WRS R-00272 Pending NM	*Pachydactylus affinis*	30/09/2004	A	P Voucher
WRS R-00278/a/b Pending NM	*Pachydactylus affinis*	30/09/2004	A	P Voucher
WRS R-00280 Pending NM	*Pachydactylus affinis*	10/10/2004	A	P Voucher
WRS R-00281 Pending NM	*Pachydactylus affinis*	10/10/2004	A	P Voucher
WRS R-00282	*Pachydactylus affinis*	10/10/2004	A	
WRS R-00284	*Pachydactylus affinis*	10/10/2004	A	P Voucher

Pending NM				
WRS R-00285	*Pachydactylus affinis*	10/10/2004	A	Sight
WRS R-00287	*Pachydactylus affinis*	10/10/2004	A	Sight
WRS R-00289 Pending NM	*Pachydactylus affinis*	10/10/2004	A	P Voucher
WRS R-00290 Pending NM	*Pachydactylus affinis*	10/10/2004	A	P Voucher
WRS R-00291 Pending NM	*Pachydactylus affinis*	10/10/2004	A	P Voucher
WRS R-00356 Pending NM	*Pachydactylus affinis*	04/09/2005	A	P Voucher
WRS (A) R-00074	*Pachydactylus affinis/capensis*	00/00/1990	A	Sight
WRS (A) R-00075	*Pachydactylus affinis/capensis*	00/00/1990	A	Sight
WRS (A) R-00119	*Pachydactylus affinis/capensis*	01/03/1992	A	Sight
WRS (A) R-00153	*Pachydactylus affinis/capensis*	19/07/1992	X	Sight
WRS (A) R-00158	*Pachydactylus affinis/capensis*	02/08/1992	X	Sight
WRS (A) R-00159	*Pachydactylus affinis/capensis*	02/08/1992	X	Sight
WRS (A) R-00162	*Pachydactylus affinis/capensis*	02/08/1992	X	Sight
WRS (A) R-00163	*Pachydactylus affinis/capensis*	02/08/1992	X	Sight
WRS (A) R-00175	*Pachydactylus affinis/capensis*	11/10/1992	A	Sight
Family: Gerrhosauridae				
WRS (A) R-00078	*Gerrhosaurus flavigularis*	00/00/1991	A	Sight
WRS R-00304 Pending NM	*Gerrhosaurus flavigularis*	26/12/2004	A	P Voucher
Family: Scincidae Subfamily: Eugongylinae				
WRS (A) R-00154	*Panaspis wahlbergii*	19/07/1992	X	Sight
WRS (A) R-00156	*Panaspis wahlbergii*	02/08/1992	X	Sight
WRS (A) R-00169	*Panaspis wahlbergii*	04/09/1992	B	Sight
WRS (A) R-00180	*Panaspis wahlbergii*	11/10/1992	B	Sight
WRS (A) R-00436	*Panaspis wahlbergii*	07/09/1995	B	Sight
WRS R-00032 TM83463	*Panaspis wahlbergii*	18/06/2000	A	P Voucher
WRS R-00033 TM83462	*Panaspis wahlbergii*	18/06/2000	A	P Voucher
WRS R-00034 TM83461	*Panaspis wahlbergii*	18/06/2000	A	P Voucher
WRS R-00039	*Panaspis wahlbergii*	18/09/2000	A	Sight
WRS R-00124	*Panaspis wahlbergii*	06/07/2002	A	Sight
WRS R-00141	*Panaspis wahlbergii*	31/08/2002	A	Sight
WRS R-00170	*Panaspis wahlbergii*	22/02/2003	A	Sight
Family: Scincidae Subfamily: Mabuyinae				
WRS (A) R-00045	*Trachylepis capensis*	00/00/1988	X	Sight
WRS (A) R-00116	*Trachylepis capensis*	19/01/1992	C	Sight
WRS (A) R-00118	*Trachylepis capensis*	01/03/1992	A	Sight
WRS (A) R-00121	*Trachylepis capensis*	20/03/1992	C	Sight
WRS (A) R-00168	*Trachylepis capensis*	04/09/1992	B	Sight
WRS (A) R-00173	*Trachylepis capensis*	28/09/1992	C	Sight
WRS (A) R-00176	*Trachylepis capensis*	11/10/1992	A	Sight
WRS R-00140	*Trachylepis capensis*	31/08/2002	A	Photographic

WRS R-00166 TM85147	*Trachylepis capensis*	22/02/2003	A	P Voucher
WRS R-00305	*Trachylepis capensis*	26/12/2004	A	Photographic
WRS R-00306 Pending NM	*Trachylepis capensis*	26/12/2004	A	P Voucher
WRS R-00795	*Trachylepis capensis*	07/10/2011	A	Photographic
WRS R-00262	*Trachylepis punctatissima*	09/08/2004	X	Sight
WRS R-00431	*Trachylepis punctatissima*	11/11/2006	X	Sight
WRS R-00438	*Trachylepis punctatissima*	09/12/2006	X	Sight
WRS R-00440	*Trachylepis punctatissima*	31/12/2006	X	Sight
WRS R-00455	*Trachylepis punctatissima*	14/01/2007	X	Sight
WRS R-00544	*Trachylepis punctatissima*	29/09/2007	X	Sight
WRS R-00596	*Trachylepis punctatissima*	30/12/2007	X	Sight
WRS R-00674	*Trachylepis punctatissima*	13/08/2009	X	Sight
WRS R-00724	*Trachylepis punctatissima*	01/01/2010	X	Sight
WRS R-00852	*Trachylepis punctatissima*	10/07/2012	X	Photographic
Family: Lacertidae				
WRS (A) R-00077	*Nucras lalandii*	00/00/1991	A	Sight
WRS R-00040	*Nucras lalandii*	18/06/2000	A	Photographic
Family: Varanidae				
WRS (A) R-00040	*Varanus niloticus*	00/00/1990	B	Sight
Family: Agamidae				
WRS (A) R-00076	*Agama aculeata distanti*	00/00/1990	A	Sight
WRS (A) R-00155	*Agama aculeata distanti*	02/08/1992	X	Sight
WRS R-00145	*Agama aculeata distanti*	31/08/2002	A	Photographic
Family: Chamaeleonidae				
WRS (A) R-00110	*Chamaeleo dilepis*	00/00/1988	X	Sight
WRS R-00125 TM84595	*Chamaeleo dilepis*	06/07/2002	A	P Voucher
WRS R-00126 TM84598	*Chamaeleo dilepis*	06/07/2002	A	P Voucher
WRS R-00146	*Chamaeleo dilepis*	31/08/2002	A	
WRS R-00355 Pending NM	*Chamaeleo dilepis*	04/09/2005	A	P Voucher
WRS R-00971	*Chamaeleo dilepis*	22/02/2015	X	Photographic
WRS R-00972	*Chamaeleo dilepis*	22/02/2015	X	Photographic
Order: Squamata – Serpentes				
Family: Leptotyphlopidae				
WRS R-00123	*Leptotyphlops scutifrons scutifrons*	06/07/2002	A	Photographic
WRS (A) R-00164	*Leptotyphlops sp.*	02/08/1992	X	Sight
Family: Typhlopidae				
WRS R-00038	*Afrotyphlops bibronii*	18/06/2000	A	Sight
WRS R-00046	*Afrotyphlops bibronii*	23/09/2000	A	Sight
WRS R-00047	*Afrotyphlops bibronii*	23/09/2000	A	Sight
WRS R-00052 TM84298	*Afrotyphlops bibronii*	17/10/2000	A	P Voucher
WRS R-00053	*Afrotyphlops bibronii*	17/10/2000	A	Sight
WRS R-00300	*Afrotyphlops bibronii*	14/11/2004	A	Sight
WRS R-00301	*Afrotyphlops bibronii*	14/11/2004	A	Sight
WRS R-00726 Pending NM	*Afrotyphlops bibronii*	23/01/2010	X	P Voucher
Family: Pythonidae				
WRS R-00922	*Python bivittatus**	13/03/2014	X	Photographic
WRS R-00739	*Python natalensis*	25/03/2010	X	Photographic
Family: Viperidae				
WRS (A) R-00297	*Causus rhombeatus*	26/03/1994	B	Sight

Family: Lamprophiidae – Aparallactinae				
WRS (A) R-00065	*Aparallactus capensis*	00/07/1991	A	Sight
WRS (A) R-00150	*Aparallactus capensis*	19/07/1992	X	Sight
WRS (A) R-00151	*Aparallactus capensis*	19/07/1992	X	Sight
WRS (A) R-00152	*Aparallactus capensis*	19/07/1992	X	Sight
WRS (A) R-00226	*Aparallactus capensis*	24/07/1993	X	Sight
WRS (A) R-00227	*Aparallactus capensis*	24/07/1993	X	Sight
WRS (A) R-00228	*Aparallactus capensis*	24/07/1993	X	Sight
WRS (A) R-00229	*Aparallactus capensis*	24/07/1993	X	Sight
WRS (A) R-00309	*Aparallactus capensis*	10/07/1994	X	Sight
WRS (A) R-00310	*Aparallactus capensis*	10/07/1994	X	Sight
WRS (A) R-00605	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00606	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00607	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00608	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00609	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00610	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00611	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00612	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00613	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00614	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00615	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00616	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00617	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00618	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00619	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00620	*Aparallactus capensis*	05/07/1996	A	Sight
WRS (A) R-00626	*Aparallactus capensis*	23/07/1996	A	Photographic
WRS (A) R-00627	*Aparallactus capensis*	23/07/1996	A	Photographic
WRS (A) R-00628	*Aparallactus capensis*	23/07/1996	A	Photographic
WRS (A) R-00629	*Aparallactus capensis*	23/07/1996	A	Photographic
WRS (A) R-00630	*Aparallactus capensis*	23/07/1996	A	Photographic
WRS (A) R-00631	*Aparallactus capensis*	23/07/1996	A	Photographic
WRS (A) R-00632	*Aparallactus capensis*	23/07/1996	A	Photographic
WRS (A) R-00633	*Aparallactus capensis*	23/07/1996	A	Photographic
WRS (A) R-00635	*Aparallactus capensis*	23/07/1996	A	Sight
WRS (A) R-00636	*Aparallactus capensis*	23/07/1996	A	Sight
WRS (A) R-00637	*Aparallactus capensis*	23/07/1996	A	Sight
WRS (A) R-00638	*Aparallactus capensis*	23/07/1996	A	Sight
WRS (A) R-00639	*Aparallactus capensis*	23/07/1996	A	Sight
WRS (A) R-00640	*Aparallactus capensis*	23/07/1996	A	Sight
WRS (A) R-00641	*Aparallactus capensis*	23/07/1996	A	Sight
WRS R-00014 TM83467	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00015 TM83468	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00016 TM83469	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00017 TM83470	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00018 TM83471	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00019 TM83472	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00020 TM83473	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00021 TM83474	*Aparallactus capensis*	18/06/2000	A	P Voucher

WRS R-00022 TM83475	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00023 TM83476	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00024 TM83477	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00025 TM83478	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00026 TM83479	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00027 TM83480	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00028 TM83481	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00029 TM83482	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00030 TM83483	*Aparallactus capensis*	18/06/2000	A	P Voucher
WRS R-00045	*Aparallactus capensis*	23/09/2000	A	Sight
WRS R-00128	*Aparallactus capensis*	06/07/2002	A	Sight
WRS R-00133	*Aparallactus capensis*	06/07/2002	A	Sight
WRS R-00134	*Aparallactus capensis*	06/07/2002	A	Sight
WRS R-00135	*Aparallactus capensis*	06/07/2002	A	Sight
WRS R-00136	*Aparallactus capensis*	06/07/2002	A	Sight
WRS R-00137	*Aparallactus capensis*	06/07/2002	A	Sight
WRS R-00138	*Aparallactus capensis*	06/07/2002	A	Sight
WRS R-00139	*Aparallactus capensis*	06/07/2002	A	Sight
WRS R-00167	*Aparallactus capensis*	22/02/2003	A	Photographic
WRS R-00273	*Aparallactus capensis*	30/09/2004	A	Preserved Voucher
WRS R-00274	*Aparallactus capensis*	30/09/2004	A	Preserved Voucher
WRS R-00275	*Aparallactus capensis*	30/09/2004	A	Preserved Voucher
WRS R-00276	*Aparallactus capensis*	30/09/2004	A	Preserved Voucher
WRS R-00288	*Aparallactus capensis*	10/10/2004	A	Preserved Voucher
WRS R-00293	*Aparallactus capensis*	10/10/2004	A	Preserved Voucher
WRS R-00294	*Aparallactus capensis*	10/10/2004	A	Preserved Voucher
WRS R-00295	*Aparallactus capensis*	10/10/2004	A	Preserved Voucher
WRS R-00296	*Aparallactus capensis*	17/10/2004	A	Sight
WRS R-00297	*Aparallactus capensis*	17/10/2004	A	Preserved Voucher
WRS R-00298	*Aparallactus capensis*	17/10/2004	A	Preserved Voucher
WRS R-00299	*Aparallactus capensis*	17/10/2004	A	Preserved Voucher
WRS R-00352	*Aparallactus capensis*	04/09/2005	A	Preserved Voucher
WRS R-00353	*Aparallactus capensis*	04/09/2005	A	Preserved Voucher
WRS R-00357	*Aparallactus capensis*	04/09/2005	A	Preserved Voucher
Family: Lamprophiidae – Lamprophiinae				
WRS (A) R-00062	*Boaedon capensis*	00/07/1991	A	Sight
WRS (A) R-00063	*Boaedon capensis*	00/07/1991	A	Sight
WRS (A) R-00117	*Boaedon capensis*	01/03/1992	A	Sight
WRS (A) R-00167	*Boaedon capensis*	02/08/1992	X	Sight
WRS (A) R-00283	*Boaedon capensis*	04/01/1994	X	Sight
WRS (A) R-00320	*Boaedon capensis*	01/12/1994	X	Sight
WRS (A) R-00434	*Boaedon capensis*	07/09/1995	B	Sight
WRS R-00041	*Boaedon capensis*	18/06/2000	A	Sight
WRS (A) R-00002	*Lamprophis aurora*	00/00/1978	X	Sight
WRS (A) R-00052	*Lamprophis aurora*	00/11/1990	A	Sight
WRS (A) R-00053	*Lamprophis aurora*	00/00/1990	A	Sight
WRS (A) R-00054	*Lamprophis aurora*	00/06/1991	A	Sight
WRS (A) R-00055	*Lamprophis aurora*	00/07/1991	A	Sight
WRS (A) R-00056	*Lamprophis aurora*	00/07/1991	A	Sight

WRS (A) R-00057	*Lamprophis aurora*	00/07/1991	A	Sight
WRS (A) R-00058	*Lamprophis aurora*	00/07/1991	A	Sight
WRS (A) R-00059	*Lamprophis aurora*	00/08/1991	A	Sight
WRS (A) R-00060	*Lamprophis aurora*	00/11/1991	B	Sight
WRS (A) R-00061	*Lamprophis aurora*	00/11/1991	A	Sight
WRS (A) R-00621	*Lamprophis aurora*	05/07/1996	A	Photographic
WRS R-00042	*Lamprophis aurora*	12/04/2000	X	Sight
WRS R-00277	*Lamprophis aurora*	30/09/2004	A	Photographic
WRS R-00639	*Lamprophis aurora*	03/12/2008	X	Photographic
WRS R-00923	*Lamprophis aurora*	24/03/2014	X	Photographic
WRS R-01013	*Lamprophis aurora*	26/01/2016	X	Photographic
WRS (A) R-00198 TM78644	*Lycodonomorphus inornatus*	08/01/1993	X	P Voucher
WRS (A) R-00073	*Lycodonomorphus rufulus*	00/01/1991	C	Sight
WRS (A) R-00171	*Lycodonomorphus rufulus*	18/09/1992	C	Sight
WRS (A) R-00172	*Lycodonomorphus rufulus*	18/09/1992	C	Sight
WRS (A) R-00181	*Lycodonomorphus rufulus*	22/10/1992	C	Sight
WRS (A) R-00437	*Lycodonomorphus rufulus*	07/09/1995	C	Sight
WRS R-00183 TM85151	*Lycodonomorphus rufulus*	11/10/2003	X	P Voucher
WRS (A) R-00046	*Lycophidion capense capense*	00/00/1990	A	Sight
WRS (A) R-00047	*Lycophidion capense capense*	00/00/1990	A	Sight
WRS (A) R-00048	*Lycophidion capense capense*	00/00/1991	A	Photographic
WRS (A) R-00174	*Lycophidion capense capense*	11/10/1992	A	Sight
WRS R-00035 TM83464	*Lycophidion capense capense*	18/06/2000	A	P Voucher
WRS R-00036 TM83465	*Lycophidion capense capense*	18/06/2000	A	P Voucher
WRS R-00037 TM83466	*Lycophidion capense capense*	18/06/2000	A	P Voucher
WRS R-00051	*Lycophidion capense capense*	17/10/2000	A	Sight
WRS R-00132	*Lycophidion capense capense*	06/06/2002	A	Sight
WRS R-00354	*Lycophidion capense capense*	04/09/2005	A	Sight
Family: Lamprophiidae – Psammophiinae				
WRS (A) R-00051	*Psammophis crucifer*	00/00/1991	A	Sight
WRS (A) R-00064	*Psammophylax rhombeatus*	00/11/1990	A	Photographic
WRS (A) R-00170	*Psammophylax rhombeatus*	04/09/1992	B	Sight
WRS (A) R-00182	*Psammophylax rhombeatus*	03/11/1992	B	Sight
WRS (A) R-00711	*Psammophylax rhombeatus*	17/11/1996	A	Sight
WRS (A) R-00912	*Psammophylax rhombeatus*	15/11/1999	A	Sight
WRS (A) R-00913	*Psammophylax rhombeatus*	15/11/1999	A	Sight
WRS R-00043	*Psammophylax rhombeatus*	13/09/2000	A	Sight
WRS R-00044	*Psammophylax rhombeatus*	13/09/2000	A	Sight
WRS R-00054	*Psammophylax rhombeatus*	17/10/2000	A	Photographic
WRS R-00055	*Psammophylax rhombeatus*	17/10/2000	A	Photographic
WRS R-00143	*Psammophylax rhombeatus*	31/08/2002	A	Sight
WRS R-00144	*Psammophylax rhombeatus*	31/08/2002	A	Sight
WRS R-00163	*Psammophylax rhombeatus*	22/02/2003	A	Sight
WRS R-00302	*Psammophylax rhombeatus*	21/11/2004	A	Photographic
Family: Lamprophiidae – Pseudaspidinae				
WRS (A) R-00049	*Pseudaspis cana*	00/12/1990	A	Photographic
WRS (A) R-00050	*Pseudaspis cana*	00/02/1991	A	Photographic
WRS (A) R-00213	*Pseudaspis cana*	19/03/1993	X	Sight
WRS (A) R-00314	*Pseudaspis cana*	21/09/1994	X	Sight
WRS (A) R-00315	*Pseudaspis cana*	21/09/1994	X	Sight
WRS R-00267	*Pseudaspis cana*	30/09/2004	A	Photographic
WRS R-00329	*Pseudaspis cana*	06/05/2005	X	Sight
WRS R-00730	*Pseudaspis cana*	17/02/2010	X	Photographic

Family: Lamprophiidae – Pseudoxyrhophiinae				
WRS (A) R-00043	*Duberria lutrix*	00/00/1988	X	Sight
Family: Elapidae				
WRS (A) R-00544 TM80136	*Elapsoidea sundevallii media*	31/01/1996	X	P Voucher
WRS (A) R-00634	*Elapsoidea sundevallii media*	23/07/1996	A	Sight
WRS R-00168 TM85148	*Elapsoidea sundevallii media*	22/02/2003	A	P Voucher
WRS (A) R-00001	*Hemachatus haemachatus*	00/00/1977	X	Sight
WRS (A) R-00044	*Hemachatus haemachatus*	00/00/1988	C	Sight
WRS (A) R-00067	*Hemachatus haemachatus*	00/10/1990	B	Sight
WRS (A) R-00068	*Hemachatus haemachatus*	00/11/1990	C	Sight
WRS (A) R-00069	*Hemachatus haemachatus*	00/01/1991	A	Sight
WRS (A) R-00070	*Hemachatus haemachatus*	00/01/1991	B	Sight
WRS (A) R-00071	*Hemachatus haemachstus*	00/02/1990	B	Sight
WRS (A) R-00302	*Hemachatus haemachatus*	10/05/1994	B	Sight
WRS (A) R-00327	*Hemachatus haemachatus*	07/12/1994	X	Sight
WRS (A) R-00367	*Hemachatus haemachatus*	05/02/1995	B	Sight
WRS R-00738	*Hemachatus haemachatus*	10/03/2010	X	Photographic
WRS R-00771	*Hemachatus haemachatus*	08/02/2011	X	Sight
WRS R-00773	*Hemachatus haemachatus*	15/02/2011	X	Photographic
WRS R-00774	*Hemachatus haemachatus*	02/03/2011	X	Sight
WRS R-00872	*Hemachatus haemachatus*	29/01/2013	X	Photographic
WRS R-00743 Pending	*Naja (Uraeus) annulifera*	30/04/2010	X	P Voucher
Family: Colubridae – Colubrinae				
WRS (A) R-00072	*Crotaphopeltis hotamboeia*	00/02/1991	B	Sight
WRS (A) R-00183	*Crotaphopeltis hotamboeia*	15/11/1992	X	Sight
WRS (A) R-00066	*Dasypeltis scabra*	00/00/1991	A	Sight
WRS (A) R-00157	*Dasypeltis scabra*	02/08/1992	X	Sight
WRS (A) R-00160	*Dasypeltis scabra*	02/08/1992	X	Sight
WRS (A) R-00161	*Dasypeltis scabra*	02/08/1992	X	Sight
WRS (A) R-00165	*Dasypeltis scabra*	02/08/1992	X	Sight
WRS (A) R-00166	*Dasypeltis scabra*	02/08/1992	X	Sight
WRS (A) R-00177	*Dasypeltis scabra*	11/10/1992	A	Sight
WRS (A) R-00178	*Dasypeltis scabra*	11/10/1992	A	Sight
WRS (A) R-00179	*Dasypeltis scabra*	11/10/1992	A	Sight
WRS (A) R-00230	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00231	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00232	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00233	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00234	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00235	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00236	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00237	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00238	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00239	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00240	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00241	*Dasypeltis scabra*	24/07/1993	X	Sight
WRS (A) R-00625	*Dasypeltis scabra*	23/07/1996	A	Photographic
WRS (A) R-00644	*Dasypeltis scabra*	27/08/1996	A	Sight
WRS (A) R-00645	*Dasypeltis scabra*	27/08/1996	A	Sight
WRS R-00130	*Dasypeltis scabra*	06/07/2002	A	Photographic
WRS R-00131	*Dasypeltis scabra*	06/07/2002	A	Photographic
WRS R-00283	*Dasypeltis scabra*	10/10/2004	A	Preserved Voucher
WRS R-00286	*Dasypeltis scabra*	10/10/2004	A	Preserved Voucher
WRS R-00292	*Dasypeltis scabra*	10/10/2004	A	Preserved Voucher
WRS R-00377	*Pantherophis alleghaniensis**	24/12/2005	X	Photographic

WRS R-00997	*Pantherophis guttatus**	21/08/2015	X	Photographic
WRS R-01039	*Pantherophis obsoletus**	21/12/2016	X	Photographic

Supplementary Table S4.2: Snake diversity in the Johannesburg Quarter Degree 2628AA.

Note: All records from 2628AA and adjacent quarter degree grid cells have been included, taken from the Atlas and Red List of the Reptiles of South Africa, Lesotho and Swaziland (Bates et al., 2014).

Key:

● Denotes species recorded from that quarter degree grid cell. Numbers refer to records in the Warren R. Schmidt Herpetological Data & Field Records Database.

S = Predominantly Savanna species

G = Predominantly Grassland species

S/G = Savanna and Grassland species

E = Exotic species

2527DD	2528CC	2528CD
2627BB	2628AA	2628AB
2627BD	2628AC	2628AD

Species:	**Primary Biome**	**2527DD**	**2528CC**	**2528CD**	**2627BB**	**2628AA**	**2628AB**	**2627BD**	**2628AC**	**2628AD**
Family: Leptotyphlopidae (Thread Snakes)										
Leptotyphlops distanti Boulenger, 1892	S	●	●	●	●					
Leptotyphlops incognitus Broadley & Watson, 1976	S		●				●			
Leptotyphlops scutifrons scutifrons (Peters, 1854)	S/G	●	●	●	●	●2				
Leptotyphlops scutifrons conjunctus (Jan, 1861)	S/G		●			●		●2	●	●
Family: Typhlopidae (Blind Snakes)										
Afrotyphlops bibronii (A. Smith, 1846)	S/G	●	●2	●	●	●8	●		●3	●
Rhinotyphlops lalandei (Schlegel, 1839)	S/G	●	●		●			●	●	
Family: Pythonidae (Pythons)										
Python bivittatus Khul, 1820	E					1				
Python natalensis A. Smith, 1840	S		●		●	1				
Family: Viperidae Subfamily: Viperinae (Adders)										
Bitis arietans arietans (Merrem, 1820)	S/G	●	●1	●	●	●			●	●
Bitis caudalis (A. Smith, 1839)	S	●	●							

Causus rhombeatus (Lichtenstein, 1823)	S/G	●	●	●	●	●1		●	●	●
Family: Lamprophiidae Subfamily: Aparallactinae										
Amblyodipsas polylepis polylepis (Bocage, 1873)	S		●			●				
Aparallactus capensis (A. Smith, 1849)	S/G	●1	●16	●	●2	●83	●1	●	●6	●
Family: Lamprophiidae Subfamily: Atractaspidinae										
Atractaspis bibronii A. Smith, 1849	S	●	●	●	●	●	●	●	●	
Atractaspis duerdeni Gough, 1907	S		●							
Homoroselaps dorsalis (A. Smith, 1849)	G	●	●			●		●	●	
Homoroselaps lacteus (Linnaeus, 1758)	G		●		●	●			●	●
Family: Lamprophiidae Subfamily: Lamprophiinae										
Boaedon capensis (Duméril, Bibron & Duméril, 1854)	S/G	●3	●4	●	●1	●11	●	●1	●1	●
Gonionotophis capensis capensis (A. Smith, 1847)	S		●			●				
Lamprophis aurora (Linnaeus, 1758)	G		●	●	●	●19	●	1	●1	●
Lycodonomorphus inornatus (Duméril, Bibron & Duméril, 1854)	S/G		●		●	●1	●	1	●1	
Lycodonomorphus rufulus (Lichtenstein, 1823)	S/G		●	●	●3	●6	●1		●3	●
Lycophidion capense capense (A. Smith, 1831)	S/G	●1	●1	●	●	●11	●	●	●1	●
Family: Lamprophiidae Subfamily: Psammophiinae (Sand & Grass Snakes)										
Psammophis brevirostris Peters, 1881	S/G	●1	●	●	●1	●		2		
Psammophis crucifer (Daudin, 1803)	G	●	●	●	●	●1		●	●	●
Psammophis subtaeniatus Peters, 1882	S					●				
Psammophis trinasalis Werner, 1902	S/G		●	●	●			1		●
Psammophylax rhombeatus (Linnaeus, 1758)	G	●	●	●	●	●14	●	●	●	●
Psammophylax tritaeniatus (Günther, 1868)	S/G	●	●	●		●			2	
Family: Lamprophiidae Subfamily: Pseudaspidinae (Mole Snakes)										
Pseudaspis cana (Linnaeus, 1758)	S/G	●	●4	●	●	●8		●	2	●
Family: Lamprophiidae Subfamily: Pseudoxyrhophiinae										
Duberria lutrix (Linnaeus, 1758)	G	●	●			●1			●	
Family: Lamprophiidae Subfamily: Prosymninae (Shovel-snouts)										
Prosymna sundevallii (A. Smith, 1849)	G	●	●	●	●	●		●	●	●1
Family: Elapidae (Cobras, Mambas and related)										
Aspidelaps scutatus scutatus (A. Smith, 1849)	S					●				
Elapsoidea sundevallii media Broadley, 1971	S/G	●	●		●	●3	●	1	●	
Hemachatus haemachatus (Bonnaterre, 1790)	G	●	28	●	●	●17	●9	●1	●1	●
Naja (Uraeus) annulifera Peters, 1854	S	●	●1	●		2	1			
Naja (Afronaja) mossambica Peters, 1854	S	●	●	●	●	●				
Family: Colubridae Subfamily: Colubrinae										
Crotaphopeltis hotamboeia (Laurenti, 1768)	S/G	●	●4	●	●	●3	●	●	●1	●
Dasypeltis scabra (Linnaeus, 1758)	S/G	●1	●5	●	●	●31		●	●1	●
Dispholidus typus typus (A. Smith, 1828)	S	●	●	●	●					
Philothamnus hoplogaster (Günther, 1863)	S/G	●	●	●		●				
Philothamnus occidentalis Broadley, 1966	S	●	●							
Philothamnus semivariegatus (A. Smith, 1847)	S	●	●	●	●					
Telescopus semiannulatus semiannulatus A. Smith, 1849	S	●	●					●		
Thelotornis capensis capensis A. Smith, 1849	S		●							
Lampropeltis californiae (Blainville, 1835)	E					2				

Lampropeltis triangulum sinaloae Williams, 1978	E					1				
Orthriophis taeniurus friesei (Werner, 1927)	E					1				
Pantherophis alleghaniensis (Holbrook, 1836)	E					2				
Pantherophis guttatus (Linnaeus, 1766)	E					1				
Pantherophis obsoletus (Say, 1823)	E					1				

Supplementary Figure 4S.1: Satellite image taken on 16 May 2002 showing development at Sites A and B.

Supplementary Figure 4S.2: Satellite image taken on 8 February 2005 showing development at Sites A and B.

Supplementary Figure 4S.3: Satellite image from 18 September 2007 showing development at Sites A and B.

Supplementary Figure 4S.4: Satellite image from 30 June 2017 showing almost complete development.

Supplementary Table S4.3: Species accounts for all amphibians and reptiles recorded from the study sites.

Amphibia: Anura

Xenopus laevis (Daudin, 1802) Common Platanna
2 records from Survey Site C: These frogs were extremely abundant along a man-made drainage channel leading from the Birch Acres Pan to Survey Site B, as well as through an enclosed storm-water culvert between 1988 and 1995. Upward of 50 individuals could be observed in one evening and they were very easy to catch once in shallow water running through the enclosed storm-water culvert.
1 record from Site X: WRS A-00104 found in a garden in Esther Park 28/04/2006.

Schismaderma carens (A. Smith, 1848) Red Toad
3 records from Site X: Interestingly, red toads were never observed or recorded from Survey Sites A, B and C, despite being common elsewhere, i.e. Midrand region, and recorded in other parts of Kempton Park.

Sclerophrys gutturalis (Power, 1927) Guttural Toad
3 records from Survey Site C: Like *Xenopus laevis*, these toads were plentiful along the drainage channel leading from the Birch Acres Pain to Survey Site B. Several dozen could be observed calling and in amplexus shortly after the onset of summer rains (although calling could be heard earlier prior to rainfall). They remained abundant between 1988 to 1995.
One additional record from Site X: WRS A-00043 President Park, Midrand 11/10/2003.

Kassina senegalensis (Duméril & Bibron, 1854) Bubbling Kassina
5 records from Survey Site C: Shortly after the 1988/1989 rains filled the Birch Acres Pan, these frogs were extremely abundant around the fringes of the pan and in surrounding grassland. They would often congregate en masse underneath building rubble such as cement slabs and concrete blocks where up to 30 individuals could be found. On one occasion, over 300 frogs were collected, counted and released (1990). As the vegetation densified, they became more difficult to locate. By 1995, the population had plummeted, but calls were still heard from Site C on 8 January 2005. No further evening visits to the Pan were conducted after 2005, so it is not known whether this population still survives.

Phrynobatrachus natalensis (A. Smith, 1849) Snoring Puddle Frogs
1 record from Survey Site B: Several frogs were observed calling around a sandy fringed pool next to Pongola River Drive in the evening during 1990. No further observations or records of this species were made after 1990.

Amietia delalandii (Duméril & Bibron, 1841) Common River Frog
2 records from Survey Site C: As with *Xenopus laevis* and *Sclerophrys gutturalis*, this frog was very common along the drainage channel, as well as inside the enclosed storm-water culvert where they would congregate in the evening and were very easy to catch. At least 20-30 individuals could be found on any given evening during

summer (1988-1996). *Amietia delalandii* will call in the middle of winter, but all activity in the survey sites was observed during the summer months.

Cacosternum boettgeri (Boulenger, 1882) Common/Boettger's Caco

4 records from Survey Site C: As with *Kassina senegalensis*, this frog remained extremely abundant around the peripheral of the Birch Acres pan and would also be found under building rubble and timber planks, carboard boxes and other material items (1988-1996). Of interest, these frogs would seldom shelter together with *Kassina senegalensis*, but a dozen or so frogs would congregate under a brick, yet a few metres away a cement slab would yield several *Kassina senegalensis*. Considering the size difference (49mm in *Kassina* and 23mm in *Cacosternum*), it is possible that *Kassina* may predate on the smaller frogs, but there are no recorded instances of amphibian predation by *Kassina senegalensis* (Channing, 2001; Minter et al., 2004).

2 additional records from Site X: WRS A-00083 from Edleen, Kempton Park on 14/11/2004 and WRS A-00199 from Esther Park, Kempton Park in January 2009. These frogs have remained abundant across Ekurhuleni and call during the day from inundated grass and shallow rain-filled puddles during the rainy season (pers. obs.).

Tomopterna cryptotis (Boulenger, 1907) Tremolo Sand Frog

1 record from Survey Site B: Several frogs were observed calling from sandy embankment at the lower end of the stream in 1990, but thereafter no further observations or calls heard.

1 record from Site X: WRS A-00063 from President Park, Midrand – calls heard in the evening of 27/11/2003.

Tomopterna natalensis (A. Smith, 1849) Natal Sand Frog

1 record from Survey Site B: One individual was discovered in 1990, but identification cannot be verified and may have been an unusually coloured *cryptotis*, as no further observations of *natalensis* have been made at any of the survey sites.

Pyxicephalus adspersus Tschudi, 1838 Giant Bullfrog

5 records from Survey Site C: The history of *Pyxicephalus adspersus* at this site is of value for future conservation management of this species in Gauteng. The first observation of this species recalled from memory was in 1978 when building extensions were underway on our property at 24 Meeu Road, Birch Acres. This is a straight-line distance of exactly 1000m north-west of the Birch Acres Pan. A large adult bullfrog was caught from a rain-filled ditch and relocated into some open grassland nearby. The species was not observed again until the 1988/1989 season of heavy rainfall which filled the Birch Acres pan (see area description for Survey Site C above). Shortly after this rainfall event, dozens of adult *Pyxicephalus adspersus* emerged and congregated in breeding aggregations (leks) around the shallow peripheral edges of the pan. Breeding continued seasonally and in one informal count, no less than 300 adult bullfrogs were counted (1989/1990 breeding season). Several thousand newly metamorphosed frogs migrated into surrounding neighbourhoods and open grasslands and received widespread press-coverage. The Kempton Park Traffic Department even went so far as to block off a road at the nearby nursery school to prevent frogs from being squashed by motor vehicles. Juvenile frogs migrated all the way through to Survey Site B, using the drainage channel running adjacent to the Eskom power lines. In the 1990/1991 season, the population numbers appeared much lower, however, they took a fatal blow when two

youngsters were caught red-handed shooting adult frogs with pellet guns. The senior author counted between 50-60 carcasses. The incident was reported to the local police station and the Transvaal Division of Nature Conservation, but no action was taken, and the incident generated very little concern. The population took a further blow between 1991 and 1995 with increasing developments on bordering properties. The most detrimental impact was the building of a refuse transfer station, followed by a fast-food outlet and townhouse development adjacent to the pan and within 100m from the water's edge. This effectively eliminated any foraging ground and aestivation sites, causing the population to experience a rapid decline. After 1993, very few adult bullfrogs were observed. Two further records were obtained from Site C after 2000: WRS A-00090 – road-killed adult at the entrance of the fast-food outlet on 08/01/2005 and WRS A-00186 – an adult seen at 12h30 hopping across the R25 road in the direction of the pan on 10/05/2008.

Pyxicephalus adspersus is known to disperse over long distances and frogs have been found in widely scattered localities far removed from known breeding sites. Other records outside of Survey Site C include: WRS A-00051 – President Park, Midrand on 22/10/2003; WRS A-0052 – Van Riebeeck Park on 26/10/2003 (this frog remained in the garden for several months and returned to the same burrow each day); WRS A-00087 – sub-adult frog found trapped in a hole in Survey Site A on 26/12/2004.

The ecology and conservation of *Pyxicephalus adspersus* has received attention in recent years (see Yetman & Ferguson, 2011; Thomas et al., 2014). Considering the population densities recorded prior to development around the Birch Acres Pan, this site could have contributed as an important conservation site for the species. However, the hydrological cycle, engineering and drainage structure of the pan is not well understood, but, historically, the area clearly supported a viable population of bullfrogs, even during the dry years preceding the late 1980s. It is not known how the high-tension power lines that run over the pan may have influenced future conservation initiatives for this species, but urban development on site effectively terminated any viable conservation efforts for the species at this site. A series of widely scattered pans from Midrand, through Kempton Park to Benoni, appears to have been important historical breeding sites for bullfrogs. In the development of conservation management plans for *Pyxicephalus adspersus*, it is critical that surrounding vegetation bordering pans be conserved to allow for effective foraging and space for aestivation.

Reptilia: Chelonia: Pelomedusidae

Pelomedusa galeata (Schoepff, 1792) Southern Marsh Terrapin

1 record from Survey Site B: A handful of terrapins were observed at the lower end of Survey Site B where the stream formed several deep pools. Sightings were around 1989/1990, thereafter no further terrapins were observed from any of the Survey Sites. However, a partial, skeletonized carapace and plastron was found at the Birch Acres Pan after 2000 (Survey Site C).

Reptilia: Squamta: Sauria

Hemidactylus mabouia (Moreau de Jonnés, 1818) Common Tropical House Gecko

1 record from Site X: WRS R-000853 was discovered in a pile of bricks at a house in Seder Road, Birchleigh, Kempton Park. FitzSimons, 1943, only recorded this species from the far northern Transvaal and eastern Transvaal lowveld, however, Roux, 1907, had a record from the Pretoria district of which FitzSimons expressed doubt.

Jacobsen, 1989, recorded it from Pretoria (2528CA). Bates et al., 2014, added additional Gauteng records for quarter degree grid cells 2528CC and 2528CD, a southern extension to Jacobsen's record. The senior author has further range extensions: WRS R-00744 – Southcrest, Alberton (2628AC/1) 14/05/2010; WRS R-00754 – Brackenhurst, Alberton (2628AC/1); WRS R-853 listed above; and WRS R-01019 – Potchefstroom, North West Province 06/07/2016. *Hemidactylus mabouia* is a commensal species living in man-made structures and buildings. It is frequently transported in goods, building materials, caravans and trailers from sub-tropical regions. Houses provide suitable micro-climates and it's expected this species will spread throughout urban areas of southern Gauteng, but at present, there are no confirmed breeding reports from Johannesburg or Ekurhuleni. Certain species of *Hemidactylus* can reproduce parthenogenically, but it is not known if *Hemidactylus mabouia* is one such species. The taxonomy of *Hemidactylus mabouia* is not resolved and cryptic lineages have been detected. Exacerbating the situation is the ease of translocation from different source populations. WRS R-00744 from Southcrest appeared different (in scalation and colouration) to other *Hemidactylus* from Gauteng. Unfortunately, it was not retained as a voucher specimen and released after being photographed.

Lygodactylus capensis (A. Smith, 1849) Cape Dwarf Gecko

10 records from Site X: This gecko was first noted and recorded from Kempton Park on 18/01/1992. They may have existed in some areas prior to this date but were nowhere common. Jacobsen, 1989, recorded it from grid cell 2628AA, but no further quarter degree grid cells in the south-east of Gauteng. *Lygodactylus capensis* is primarily a savanna species, but after 1990 there has been a population explosion and expansion into all suburban areas of Gauteng and is now one of the most ubiquitous reptiles in Johannesburg and surrounds. They are particularly common in well-wooded gardens with precast and brick walls, where they shelter and nest inside the wall cavities. Communal nesting sites have been found underneath roof tiles and inside precast walls (pers. obs.).

4 records from Survey Site A: Although largely confined to suburban gardens, four specimens were collected from building rubble in grassland in Survey Site A – WRS R-00164 (22/02/2003) and WRS R-00265/WRS R-00266/WRS R-00279 (30/09/2004).

Pachydactylus affinis Boulenger, 1896 Transvaal Thick-toed Gecko

24 records from Survey Site A: These geckos were abundant in Survey Site A and were commonly found inside moribund termitaria, as well as under building rubble, particularly concrete slabs. Females usually lay two hard-shelled eggs which adhere to each other. Eggs were often located under building rubble.

1 record from Survey Site B.

An additional 9 records are labelled as *Pachydactylus affinis/capensis* and are from Sites A and X. These are earlier records where identification was not confirmed as they are mostly sight records. However, all subsequent records were identified as *affinis* and several vouchers deposited in the National Museum, Bloemfontein. The *Pachydactylus affinis/capensis* group is currently under revision (Buyi Makhubo, National Museum pers. comm.).

Gerrhosaurus flavigularis Wiegmann, 1828 Yellow-throated Plated Lizard

2 records from Site A: Although only logged twice, these lizards were abundant in Survey Sites A, B and C between 1988 and 2005. They were found in open, broken ground with scattered bricks and building rubble, as well as in dense grass where they are superbly camouflaged. They appear adaptable to disturbed land and have

been observed in open patches between urban suburbia, but not in urban gardens. The last one recorded from Site A was WRS R-00304 on 26/12/2004.

Panaspis wahlbergii (A. Smith, 1849) Wahlberg's Snake-eyed Skink

7 records from Site A: These small skinks are common and found under building rubble and inside moribund termite mounds. All records from Site A were taken between 2000 and 2003.

3 records from Site B: Common in Site B with records taken between 1992 and 1995.

2 records from Site X: Found inside moribund termite mounds during winter.

Trachylepis capensis (Gray, 1831) Cape Skink

7 records from Site A: This was a commonly encountered skink with records taken between 1992 and the last record (WRS R-00795) on 07/10/2011 on a stand being developed. This was the last reptile record taken in Survey Site A. All skinks recorded prior to 2004 were of the usual striped/checkered pattern, whereas all subsequent records from Site A were of a plain copper brown (WRS R-00305; WRS R-00306 and WRS R-00795). Whether this is attributable to a changing environment (more open ground than grassland) is unknown as the sample size is too small but would make for an interesting future line of enquiry. The checkered pattern would stand out more prominently on open ground compared with the plain copper brown form and may server as a predator avoidance strategy.

1 record from Site B: Normal checkered pattern on 04/09/1992.

3 records from Site C: Normal checkered pattern forms found under or basking on building rubble.

Note: *Trachylepis capensis* is often noted to be adaptable to urban gardens (Branch, 1998), but this does not appear to be the case in Gauteng (pers. obs.). *Trachylepis capensis* prefers well-vegetated as well as rocky open ground and is more of a terrestrial species compared with *Trachylepis punctatissima* which is extremely prolific in urban gardens and even industrial factories. *Trachylepis punctatissima* is also much more adept at climbing than *T. capensis* and therefore occupies brick and pre-cast walls, houses and outbuildings.

Trachylepis punctatissima (A. Smith, 1849) Speckled Rock Skink

10 records: All from urban gardens (Site 'X'). This skink was never observed or recorded from Sites A, B and C, but is one of the most prolific skinks in urban areas, including parks, gardens and even around industrial factories and commercial shopping centres. The first record was taken on 09/08/2004 but was no doubt present long before this date (Jacobsen, 1989, records it from grid cell 2628AA). The biomass per hectare in urban areas would make for an interesting study. In one urban complex in Germiston, Gauteng, the senior auhtor has recorded a density of 25-30 adult skinks in an area of approximately 5 000 square metres or 0,5 hectares. Another suburb in Edenvale, Dowerglen, where the senior author has observed a high population of these skinks, an area of approximately 100 hectares may have a population density of more than 6 000 skinks. Norval & Norval, 2007, recorded *Trachylepis punctatissima* feeding on potato chips, spaghetti, bread, cake ice-cream, jelly, mince and popcorn, which highlights how adaptable these skinks are to anthropogenic dominated urban landscapes.

Nucras lalandii (Milne-Edwards, 1829) Delalande's Sandveld Lizard

2 records from Site A: This species would appear to be either rare or secretive, as only two observations were made in 1991 and again on 18/06/2000. Both lizards were found in burrows constructed underneath concrete blocks, but elsewhere, WS has recorded them from underneath natural rocks resting on soil, usually within dense, undisturbed grassland. These lizards don't appear to be adaptable to disturbed grassland and perhaps why only two records were taken at Site A prior to development. This observation agrees with that of Masterson et al. 2009, who found that *Nucras lalandii* were only found in pristine, un-modified grasslands within Suikerbosrand Nature Reserve. However, these authors suggested that the population in Suikerbosrand appeared isolated from populations to the north and east by approximately 100-200 km, but this assessment is not correct, as they are found in grasslands near Alberton and several localities around Kempton Park and Benoni, although in small, undisturbed grasslands patches (pers. obs.).

Varanus niloticus (Linnaeus, 1762) Water/Nile Monitor Lizard
1 record from Site B: Only one sight record from 1990 at the lower-end of the stream. These large lizards were common around dams and rivers in Gauteng in the early 1990s and observed along the Jukskei, Klein Jukskei and Hennops Rivers, but populations appear to have crashed. There has been a dramatic decline observed on the South Coast of KwaZulu-Natal (WS *in prep*.), however, they still appear to be abundant in protected areas.

Agama aculeata distanti Boulenger, 1902 Eastern Ground Agama
2 records from Site A: Relatively common in the area between 1998 and 1996 with one further observation on 31/08/2002 (WRS R-00145). They prefer open ground and shelter underneath building rubble and corrugated tin sheets.
1 record from Site X.

Chamaeleo dilepis Leach, 1819 Common Flap-neck Chameleon
4 records from Site A: Two sub-adult aestivating chameleons were uncovered from beneath a rubberised sheet partially buried in soil on 06/07/2002 (WRS R-00125 and WRS R-00126). A skeletonized head of a chameleon was found impaled onto a tree branch on 21/08/2002. A fourth chameleon was discovered inside a moribund termite mound on 04/09/2005 in an area under imminent development. All four of the above chameleons were sub-adults. It was mystery how the two aestivating chameleons burrowed under the rubber-like sheeting and how WRS R-355 made its way inside the narrow chambers of the termite mound.
3 records from Site X: Chameleons were observed sporadically from urban gardens in Birch Acres between 1980 and 1988 but no further observations until 22/02/2015 when two adult chameleons were found crossing the road in Birchleigh North. These chameleons appeared to be engaging in male-male combat and were photographed and released. Road traffic, domestic cats and the use of pesticides in gardens are believed to be detrimental to chameleons in urban areas.

Reptilia: Squamta: Serpentes

Leptotyphlops scutifrons ssp. Thread Snakes

1 record from Site A and 1 record from Site X. These tiny snakes are difficult to identify, and their fossorial habits make sampling and assessment of populations difficult. The two forms or subspecies *scutifrons* and *conjunctus* are both recorded from grasslands in Gauteng.

Afrotyphlops bibronii (A. Smith, 1846) Bibron's Blind Snake

7 records from Survey Site A: This fossorial species remains an enigma in the area, as they were not observed or recorded prior to 2000 despite extensive surveys. However, a population appeared in close proximity with the first individual recorded on 18/06/2000 in a spot that had previously been searched numerous times. Despite being fossorial, *Afrotyphlops bibronii* is easy to sample as they are often found underneath rocks or concrete blocks resting on soil and therefore easily detected.

1 record from Site X: WRS R-726 was found drowned in a swimming pool in Esther Park.

Causus rhombeatus (Lichtenstein, 1823) Common/Rhombic Night Adder

1 record from Site B: These snakes don't appear to be common but are widely distributed throughout Gauteng. One adult snake was collected from a property on the border of Site B on 26/03/1994.

Aparallactus capensis (A. Smith, 1849) Cape Centipede-eater

72 records from Site A: These small snakes are prolific in grasslands and have a close affinity with moribund termite mounds. They are often found in association with *Dasypeltis scabra* and *Lamprophis aurora*, particularly during the dry winter season. Very little is known about the natural history of *Aparallactus capensis*, but they are believed to be prey specialists feeding exclusively on centipedes (Chilopoda). However, almost nothing is known of specific prey species composition, feeding strategy and hunting times. Centipedes are common within the chambers of moribund termite mounds, but it is not known if this is the primary driver attracting *Aparallactus capensis*. Thermoregulatory behaviour has been observed whereby *Aparallactus capensis* will cluster near the surface of the termite mound facing the sun (pers.obs.). As many as 30 individuals have been found in a single termite mound. Elsewhere in the survey site, they have been found singly under building rubble.

9 records from Site X: All found during winter in deserted termite mounds.

Boaedon capensis (Duméril, Bibron & Duméril, 1854) Common/Southern Brown House Snake

4 records from Site A: Surprisingly, *Boaedon capensis* did not appear to be common within the survey sites. This may be attributable to the lack of rocky outcrops where they appear to be more common (WRS pers. obs.). WRS (A) R-00062, WRS (A) R-00063 and WRS (A) R-00117 were found inside deserted termite mounds; WRS R-00041 was found within a pile of bricks.

1 record from Site B: WRS (A) R-00434 – hatchling snake found under a concrete block.

3 records from Site X: WRS (A) R-167 inside termite mound; WRS (A) R-00283 and WRS (A) R-00320 – both adult road-killed snakes on R25/Modderfontein Road.

Lamprophis aurora (Linnaeus, 1758) Aurora Snake

11 records from Site A: These snakes were common in Site A and either found inside moribund termite mounds or in building rubble. The first records are from 1990 and the last individual was found on 30/09/2004. The ones inside termite mounds were often in association with *Dasypeltis scabra* and *Aparallactus capensis*.
1 record from Site B: WRS (A) R-00060 – hatchling found underneath granite boulder on stony substrate near the stream.
5 records from Site X: WRS (A) R-00002 killed on our property in Meeu Road, Birch Acres in 1978 during building construction; WRS R-00042 – road-killed hatchling in Birchleigh North; WRS R-00639 – caught in Modderfontein Golf Course Club House in evening of 03/12/2008; WRS R-00923 – found inside industrial factory in Spartan on 24/03/2014; WRS R-01013 – hatchling caught in Umfuyaneni, Tembisa in highly disturbed area.
Note: These snakes appear highly adaptable to built-up and disturbed areas owing to their nocturnal and secretive habits. WRS has recorded them from peri-urban sites in Germiston, Spartan and Alrode.

Lycodonomorphus inornatus (Duméril, Bibron & Duméril, 1854) Olive Snake
1 record from Site X: This is a museum voucher, but the origin and locality need confirmation. However, several *L. inornatus* have been collected from the East Rand. Populations in Johannesburg appear to have declined dramatically, as they were commonly brought into the Transvaal Snake Park in the early 1990s from rocky ridges of Linksfield, Mondeor and the Klipriviersberg areas. However, despite extensive searches, no further specimens have been noted after 2000.

Lycodonomorphus rufulus (Lichtenstein, 1823) Common/Brown Water Snake
5 records from Site C: A common snake around the margins of the Birch Acres Pan between 1990 and 1996, but thereafter not observed again after development in the area. Two adult snakes were found together under a cement slab on 18/09/1992.
1 record from Site X: WRS R-00183 – a road-killed snake from President Park, Midrand on 11/10/2003.

Lycophidion capense capense (A. Smith, 1831) Cape Wolf Snake
10 records from Site A: A common species in survey site A. The first records are from 1990 and the last record was taken on 04/09/2005. These small, nocturnal constrictors feed on skinks, geckos and lacertid lizards. They have enlarged teeth which assist in anchoring into the smooth, polished scales of skinks. Four snakes were found inside deserted termite mounds and six snakes underneath building rubble.

Psammophis crucifer (Daudin, 1803) Cross-marked Grass Snake
1 record from Site A: Only one snake was observed during 1991. Of 17 snakes recorded by Masterson et al., 2009, in Suikerbosrand Nature Reserve, 9 were found in pristine grassland, 6 in rocky terrain and only 2 in modified habitat, indicating that these snakes may be sensitive to habitat transformation. They are abundant in pristine montane grassland on the Mpumalanga Escarpment (pers. obs.) and the lack of records in Survey Site A after 1991 may be indicative of the progressive degradation of the site.

Psammophylax rhombeatus (Linnaeus, 1758) Rhombic Grass Snake

12 records from Site A: These snakes were common between 1988 and 2004 and appeared highly adaptable to fragmented and degraded grassland. Females would utilise precast wall slabs as oviposition sites. *Psammophylax rhombeatus* is unique among psammophiids in that females remain with their eggs after deposition. Within the survey site, female snakes tended to seek nesting sites that had a grassy root network under the slab, possibly increasing humidity. Interestingly, only one observation was made of a juvenile actively foraging. All other records are of snakes found during the day under shelter. However, these snakes were either aestivating or nesting.
2 records from Site B: WRS (A) R-00170 – sub-adult found underneath cement blocks and rubble on 04/09/192 and WRS (A) R-00182 – adult found under precast wall slab.

Pseudaspis cana (Linnaeus, 1758) Mole Snake
3 records from Site A: WRS (A) R-00049 – large adult found under a roofing tile on a pile of building rubble; WRS (A) R-00050 – adult snake found killed on a pedestrian footpath; WRS R-00267 – juvenile found under concrete block on 30/09/2004. The presence of this juvenile indicates that the species was still breeding in the area in 2004. In some regions, such as the Western Cape, *Pseudaspis cana* appear adaptable to peri-urban areas. However, in Gauteng, this snake appears to be sensitive to urban and agricultural development, although individuals are often found in properties bordering open grassland.
5 records from Site B: WRS (A) R-00213 – juvenile from Kempton Park; WRS (A) R-00314 and WRS (A) R-00315 found together engaged in male-male combat in smallholding in Glen Austin, Midrand; WRS R-00329 – adult ebony-brown specimen seen basking on road in Modderfontein Conservation Area on 06/05/2005; WRS R-00730 – adult dug out from burrow network in a garden bordering the Modderfontein Conservation Area on 17/02/2010.

Duberria lutrx (Linnaeus, 1758) Southern Slug-eater
1 record from Site X: Only one record of three juvenile snakes dug up in the gardens of Norkem Park High School during 1988. NPHS is situated about 1 km south of Survey Site B. These snakes give birth to live young, however, no adult snake was found together with the three juveniles. These snakes may have been present in Survey Site B and the lack of records may be attributable to limited sampling at this site.

Elapsoidea sundevallii media Broadley, 1971 Highveld Garter Snake
2 records from Site A: These elapid snakes are semi-fossorial and secretive. A skeletonized snake (identified by skin remnants) was found inside a deserted termite mound on 23/07/1996 and a second live snake inside a moribund termite mound on 22/02/2003. At least two further specimens were found by other snake enthusiasts and examined by the author. A specimen from Site B found beneath a rock was photographed.
1 record from Site X: WRS (A) R-00544 from Midrand – brought into Transvaal Snake Park for identification.

Hemachatus haemachatus (Bonnaterre, 1790) Rinkhals
1 record from Site A: WRS (A) R-00069 – large adult dug up from within burrow networn in soil.
5 records from Site B: These snakes were more abundant in the moister grassland areas adjacent to the stream.
2 records from Site C: Two records from the Birch Acres Pan. One actively crossing the road and a second snake found underneath building rubble.

7 records from Site X: Seven records from scattered localities across 2628AA/2.

Crotaphopeltis hotamboeia (Laurenti, 1768) Red-lipped/Herald Snake

1 record from Site B: WRS (A) R-00072 – juvenile found in a pile of broken roofing tiles adjacent to the stream. The lack of further records may be attributed to limited sampling at this site, as these snakes are generally common where they occur.

1 record from Site X: WRS (A) R-00183 – adult found underneath a rubber dustbin adjacent to a house in President Park during rainy weather.

Dasypeltis scabra (Linnaeus, 1758) Common/Rhombic Egg-eater

12 records from Site A: Although only 11 records were taken after 1991, at least 30 individuals were found between 1988 and 1992 (collectively as WRS (A) R-00066). These snakes are abundant in Gauteng grasslands and may have a significant impact on regulating bird populations. *Dasypeltis scabra* has a wide distribution across southern Africa in most biomes. A handful of plain coloured individuals were found at this site (see Schmidt, 1999).

17 records from Site X: These records are from snakes found inside moribund termite mounds near Site A (Chloorkop/Midrand area). 12 snakes were found in one day.

Bates and Little, 2013, summarised evidence of egg predation by *Dasypeltis scabra* in the Mesic Highveld Grassland Bioregion. Three bird species were identified as having eggs predated upon in moist highland grasslands between Lydenburg and Belfast in Mpumalanga and these included African pipit (*Anthus cinnamomeus*); Cape longclaw (*Macronyx capensis*) and common quail (*Coturnix coturnix*) (Bates & Little, 2013). In a study by Lloyd et al. (2001) on Namaqua Sandgrouse (*Pterocles namaquensis*), they attributed 43,5% of eggs lost to predation to *Dasypeltis scabra*. Considering the high population densities recorded within Sites A and X, these snakes undoubtedly have a significant impact on ground-nesting grassland bird species.

Dasypeltis scabra hatchlings average 210-240 mm (Broadley, 1990; Branch, 1998) and maximum recorded sizes include a male from Ubombo (TM 19374) which measured 595 + 115 = 710 mm and a female from Inyangani Tea Estates (UM 19031) 790 + 108 = 898 mm (Broadley, 1990), although Branch (1998) records a snout-vent length of a female as 964 mm. At least 80% of snakes recorded from Sites A and X were below 500 mm total length. Bates (1990) highlighted grassland birds which lay small eggs suitable to ingestion by hatchling and juvenile *D. scabra*, particularly larks (Alaudidae).

Masterson et al. (2009) recorded 17 specimens from their survey sites in Suikerbosrand Nature Reserve which were almost evenly distributed across the sites sampled (4 from modified habitat; 8 from pristine and 5 from rocky terrain).

These snakes appear adaptable to a wide range of pristine and transformed habitats provided adequate shelter and a regular supply of bird eggs are available. However, once urban development as occurred, they are unlikely to persist in urban or peri-urban areas.

APPENDIX S4.2: Details of mammals, birds and fish recorded from the study sites.

Mammals, Birds and Fish

During the period 1988-1996, several mammal species were noted from Survey Sites A and B. Two black-backed jackal (*Canis mesomelas*) were briefly seen during one excursion in 1988. At least one sighting of a common duiker (*Sylvicapra grimmia*) was noted around the same period. However, after 1988 no further sightings of jackal or antelope were noted from the area.

Scrub hares (*Lepus saxatilis*) were abundant in the area and several were seen and flushed out from thick grass patches and scrub on each excursion into the veld. They remained abundant right into the late 1990s after which the population seemed to have crashed, as no further sightings were noted after 2000. Numerous wire snares placed about 20-30cm above ground level were regularly discovered and destroyed during 1988 to 1996. These were presumably to catch scrub hares, but no animals were ever found ensnared.

The Southern African hedgehog (*Atelerix frontalis*) was another common mammal often encountered between 1988-1992, but thereafter numbers declined rapidly and only one further hedgehog was recorded and photographed from Site A in 1995. Hedgehogs would be found under building rubble, tin sheets or occasionally foraging through thick cover and grass during overcast, cool weather. Despite the perceived decline in Sites A and B, a recent study suggests that *Atelerix frontalis* is adaptable to peri-urban and urban environments. The same study also indicated that this species is particularly common in Egoli Granite Grassland (Light, 2015). However, the study made extensive use of citizen science contributions as well as rescued animals donated to an animal rescue centre. It is of WS opinion that *Atelerix frontalis* may indeed be experiencing population declines across its range where development is taking place, based on personal observation and consensus across field workers and conservationists he has engaged with.

Several yellow mongoose (*Cynictis penicillata*) were observed in Sites A and B, but became much rarer after 2000 with no further sightings after 2003.

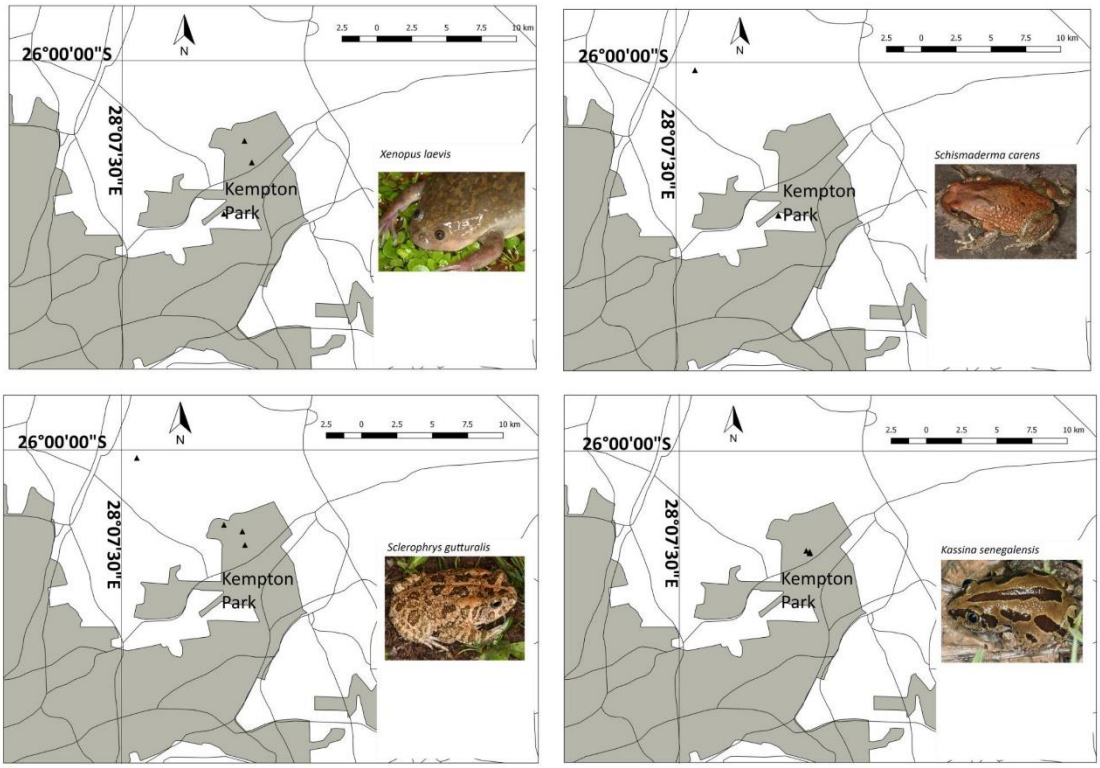
Smaller mammals noted from Sites A and B include shrews, moles and rodents. Moles were noted by the presence of mole mounds from soil, but the species involved was not noted or recorded. Dwarf shrews *Suncus spp.* were frequently found inside moribund termite mounds and often made a nest of twisted grass inside hollows within the termite nest chambers. Four-striped grass mice (*Rhabdomys pumilio*) were often seen foraging in the grass and a multi-mammate mouse (*Mastomys natalensis*) was found and photographed. Gerbils may have been present but were not identified to species. Several domestic rats (*Rattus rattus*) and mice (*Mus musculus*) were found when moving building rubble or sifting through garden material.

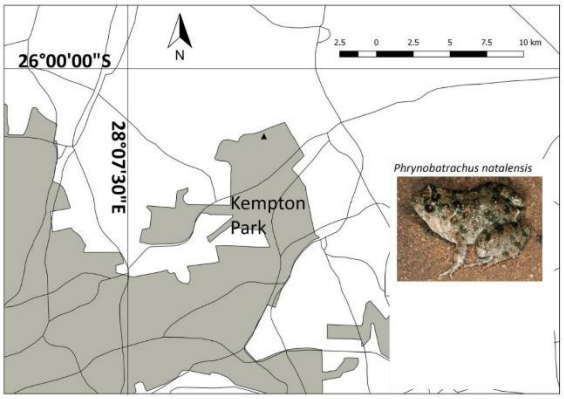
Bird diversity within the Survey Sites was not extensively noted barring a few of the larger bird species. Most notably, two species of owl were frequently flushed from thick grass and numerous road-killed individuals observed on two roads adjacent to Survey Site A – the Allandale Road (M39) and especially the Modderfontein Road (M38) between 1988-1995. These included Marsh Owls (*Asio capensis*) and African Grass-Owl (*Tyto capensis*). *Tyto capensis* is listed as Vulnerable (2015 Regional Status) (Whittington-Jones et al., *in* Taylor et al. 2015). Blue cranes (*Anthropoides paradiseus*) were often seen in moist grassland in Survey Site B between 1988-1992, but thereafter appeared to have absconded due to the increased building activity in the area. *Anthropoides paradiseus* is listed as Near Threatened (2015 Regional Status) and Vulnerable (2015 Global Status) (Shaw, in Taylor et al. 2015). The only other prominent birds included Crowned Lapwings (*Vanellus coronatus*) and Spotted

Thick-knees (*Burhinus capensis*). Korhaans were another large bird frequently flushed but the exact species was not identified.

No fish have been observed or recorded from the Birch Acres pan (Survey Site C). However, in 1991, at a storm-water culvert outlet next to Pongola River Drive on the border of Birch Acres and Norkem Park, several three-spot barbs (*Enteromius trimaculatus*) were caught in the evening while searching for frogs. These were kept in an aquarium at the Transvaal Snake Park (Halfway House) for several months.

Supplementary Figure S4.5 Distribution maps of snakes and other reptile and amphibian species recorded in the present study.

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Kempton Park
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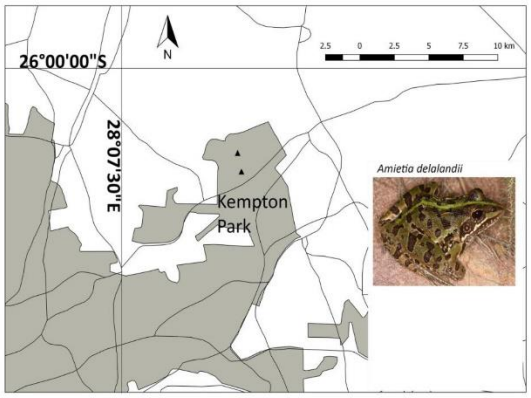
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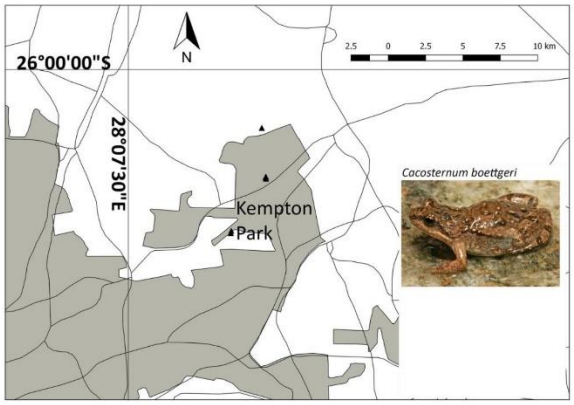
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Kempton Park
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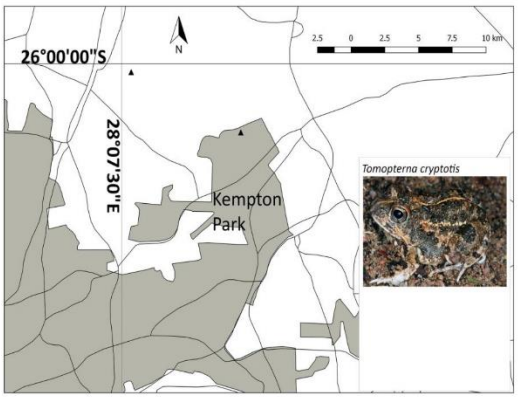
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Kempton Park
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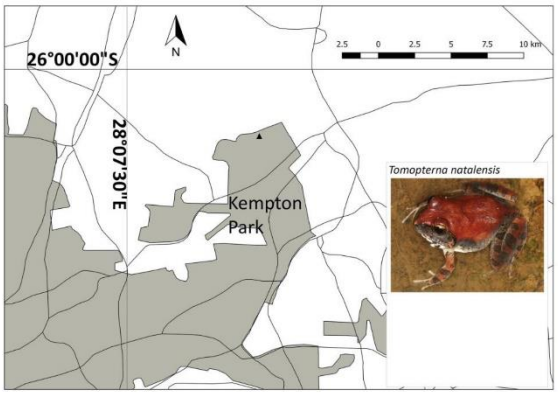
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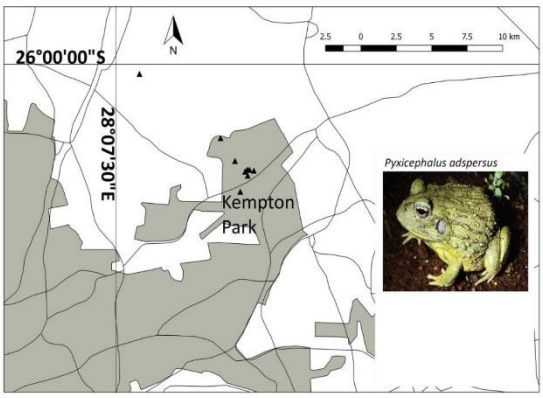
Kempton Park
Tomopterna natalensis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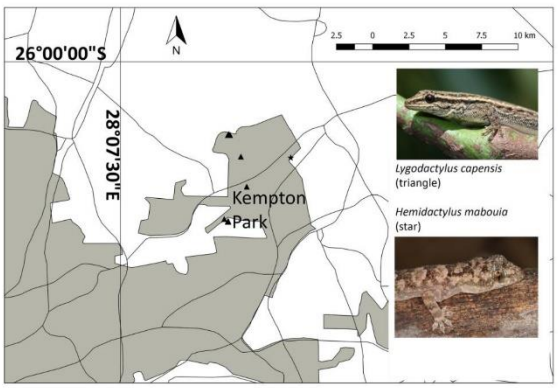
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Pyxicephalus adspersus


26°00'00"S
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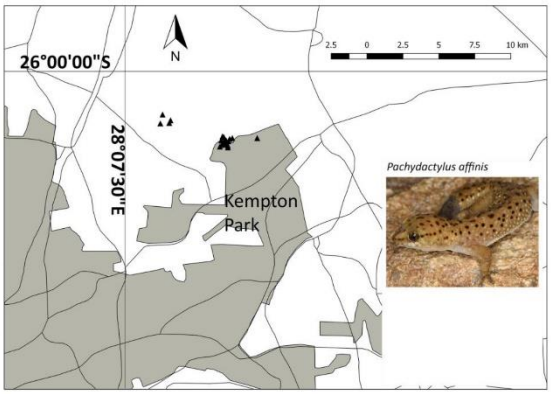
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Lygodactylus capensis
(triangle)
Hemidactylus mabouia
(star)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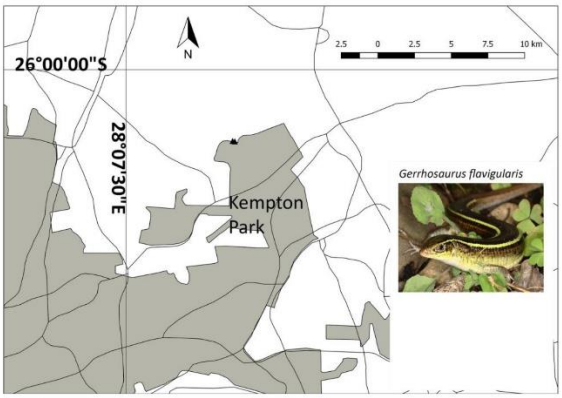
Kempton Park
Pachydactylus affinis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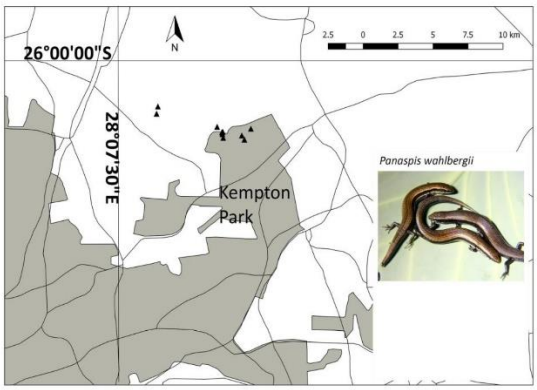
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Gerrhosaurus flavigularis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N
2.5 0 2.5 5 7.5 10 km
Kempton Park
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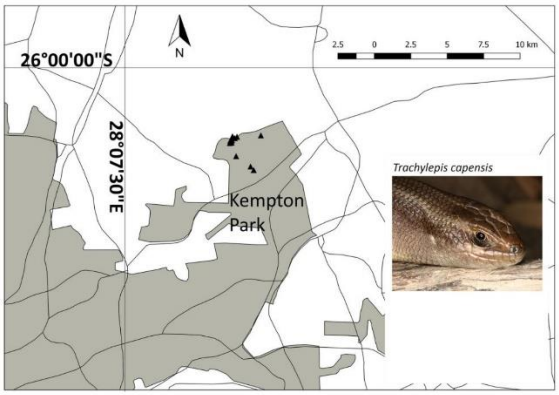
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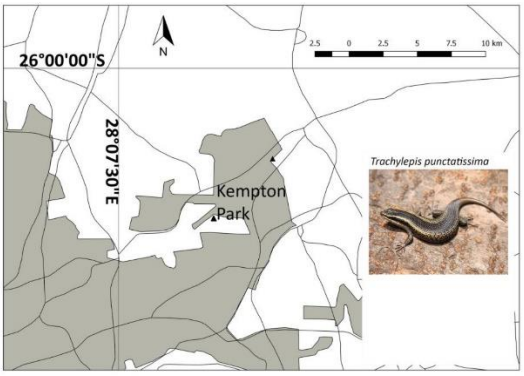
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Trachylepis capensis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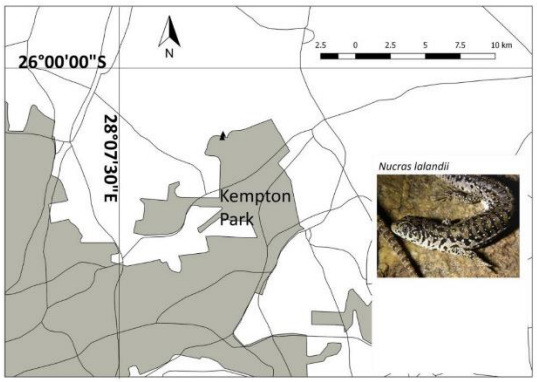
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Trachylepis punctatissima


26°00'00"S
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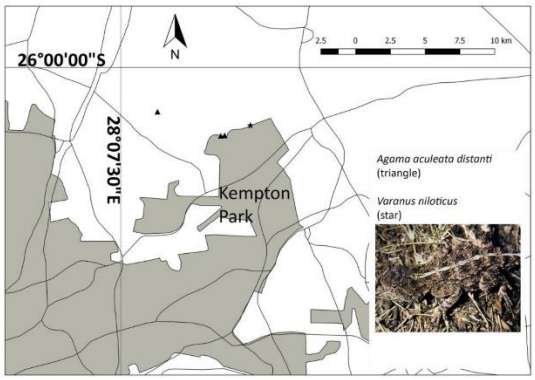
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Nucras lalandii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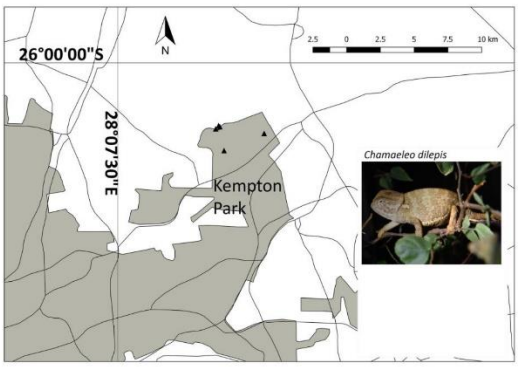
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Agama aculeata distanti
(triangle)
Varanus niloticus
(star)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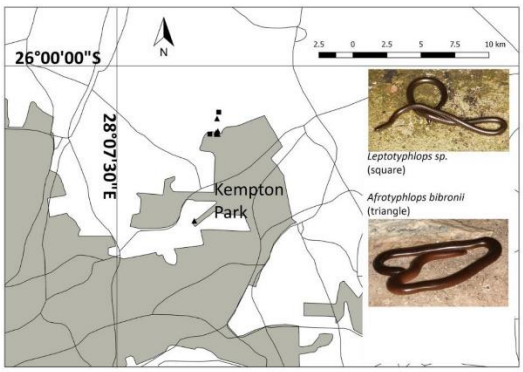
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Chamaeleo dilepis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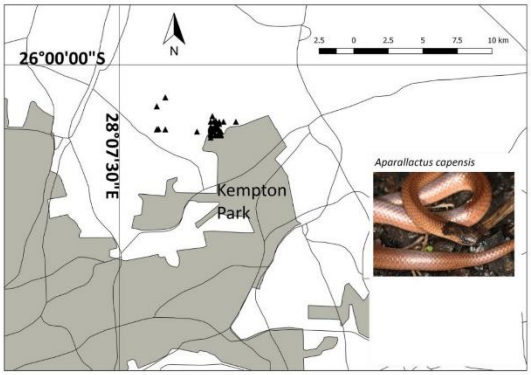
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Leptotyphlops sp.
(square)
Afrotyphlops bibronii
(triangle)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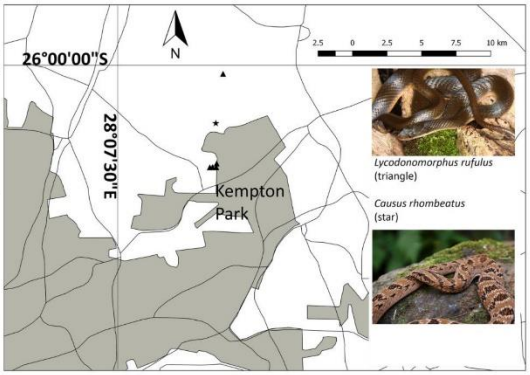
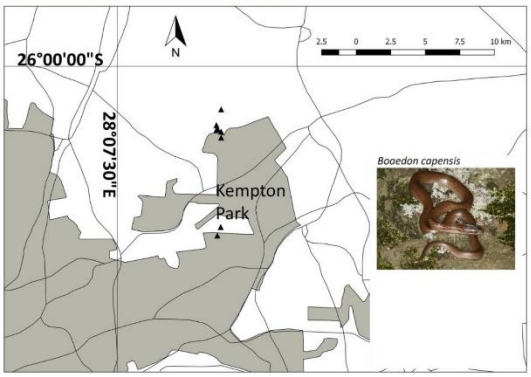
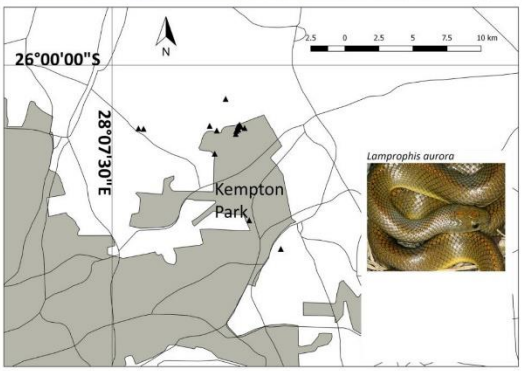
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Aparallactus capensis


26°00'00"S
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Lycodonomorphus rufulus
(triangle)
Causus rhombeatus
(star)


26°00'00"S
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Boaedon capensis


26°00'00"S
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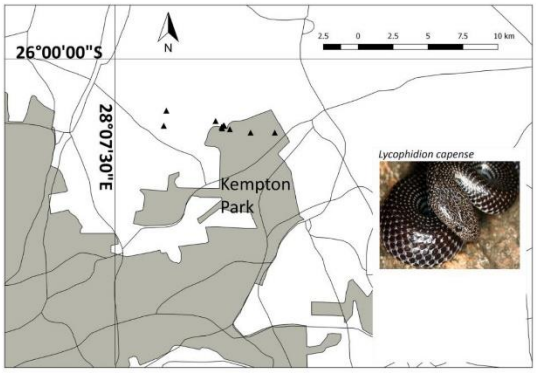
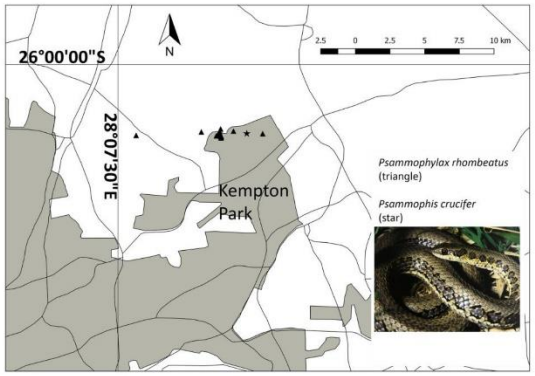
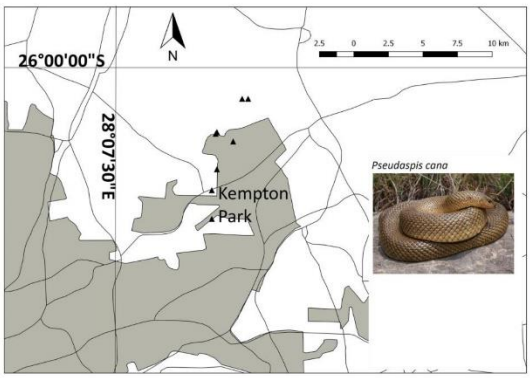
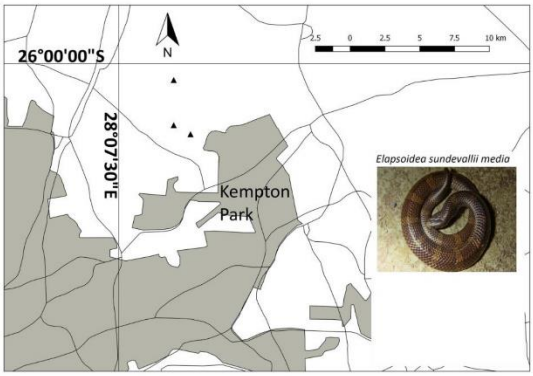
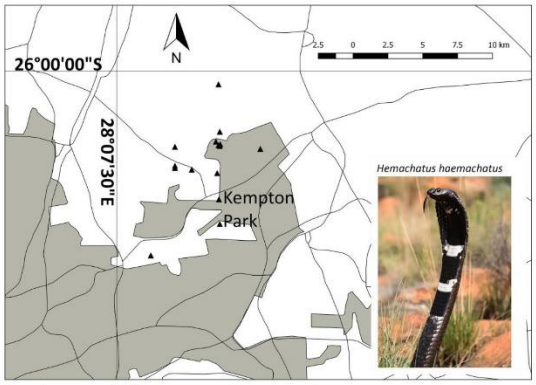
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Lamprophis aurora

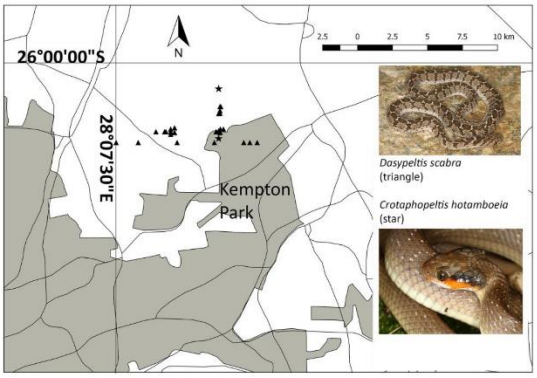

26°00'00"S
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Lycophidion capense

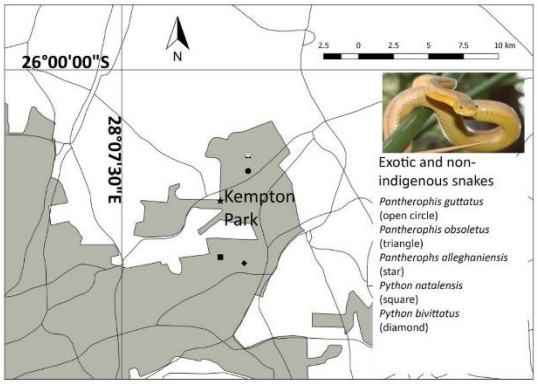

26°00'00"S
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Psammophylax rhombeatus
(triangle)
Psammophis crucifer
(star)


26°00'00"S
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Pseudaspis cana


26°00'00"S
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Elapsoidea sundevallii media


26°00'00"S
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Hemachatus haemachatus


26°00'00"S
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Dasypeltis scabra
(triangle)
Crotaphopeltis hotamboeia
(star)


26°00'00"S
28°07'30"E
N
2.5 0 2.5 5 7.5 10 km
Kempton Park
Exotic and non-indigenous snakes
Pantherophis guttatus
(open circle)
Pantherophis obsoletus
(triangle)
Pantherophs alleghaniensis
(star)
Python natalensis
(square)
Python bivittatus
(diamond)

CHAPTER 5

Herpetofauna on the South Coast of KwaZulu-Natal: composition and declines

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Formatted as a manuscript for submission to an international peer review journal

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Running header: Herpetofauna on the South Coast of KwaZulu-Natal

5.1 ABSTRACT

Amphibians and reptiles are experiencing widespread population declines globally. Habitat destruction is cited as one of the greatest contributing causes of decline. The herpetofaunal composition of a peri-urban coastal region in coastal KwaZulu-Natal, South Africa, was assessed. Data were accumulated over a period spanning 30 years during random site visits between 1988 and 2018. The species composition of frogs, lizards and snakes are presented and were analysed for occurrence and trends. Several species were noted as becoming

increasingly rare during consecutive site visits. As a result, possible contributing factors were investigated, including the observed increase in density and species diversity of alien invasive vegetation. Snakes are specifically highlighted, as a notable decline in species encounter rates was observed over three equal consecutive periods. Implications for conservation, forest management and further research direction are discussed.

Key words: KwaZulu-Natal Coastal Mosaic; Indian Ocean Coastal Belt; reptiles; amphibians; composition; population declines; invasive alien plants.

5.2 INTRODUCTION

Reptiles and amphibians are disproportionally more threatened than mammals and birds (IUCN 2006; Gardner et al., 2007). Amphibian declines are well documented, but reptiles less so (Gibbons et al., 2000; Reading et al., 2010). However, recent reports suggest that reptiles are also declining at alarming rates (Gibbons et al., 2000; Reading et al., 2010; Böhm et al., 2013). Data are lacking since reptiles have received much less research attention than birds or mammals (Böhm et al., 2013). Added to this, many reptiles are secretive and therefore difficult to study. This is more so with snakes which are possibly one of the most difficult vertebrate taxa to study in terms of population structure. Due to their ectothermic metabolism, they can remain hidden underground or inside rock crevices or tree cavities for extended periods of time, limiting observation (Mattison, 1995). Radio tracking is slowly revealing lifestyle straits of larger species like pythons, boas and vipers, but for most species, basic understanding of lifestyles and behaviour are lacking (Shine, 1998). As a result, their environmental needs, and, how they adapt to anthropogenic-induced habitat modification is mostly unknown. Long-term field studies for reptiles are also extremely rare, with a few receptions in Europe and North America (Fitch, 2006). Therefore, conservation planning and assessments for this group are

primarily based on presence/absence data inferred from museum records, and more recently with the addition of citizen science contributions to virtual museums (Bates et al., 2014).

Following a 30-year (1988-2018) period of data collection in the coastal villages and surrounds of Southport and Umtentweni, on the KwaZulu-Natal South Coast, South Africa, where presence of amphibians and reptile species were recorded. In recent years, it was noticed that several species of amphibian and reptile appeared to have become increasingly rare. Possible contributing factors were investigated as to why some species appear to have declined. The dataset was analysed to determine whether anecdotal observations taken over a long period of time could be used to quantify and identify probable species or composite population declines. Urban and agricultural development has been limited in extent, however, a notable increase in density and species composition of alien invasive vegetation has been observed. Amphibian and reptile species diversity, habitat utilisation and perceived population declines were analysed and discussed. There are relatively few long-term herpetological studies (>20 years) outside protected areas in South Africa, therefore effects of anthropogenic habitat change, and ecological succession on these taxa are largely undocumented in the peri-urban landscape.

5.3 METHODS

5.3.1 Site visits and study duration

During a period spanning 30 years (1988-2018), approximately 33 random site visits were made to the coastal villages of Southport and Umtentweni, on the KwaZulu-Natal South Coast, South Africa (Figure 5.1). Visits were not conducted as part of formal research surveys, but detailed field notes were taken during family vacations where amphibians and reptiles were recorded. In later years, several dedicated field surveys were conducted with the express purpose of recording amphibians and reptiles. During each site visit (which spanned between

1-21 days), amphibians and reptiles encountered by random chance or during dedicated visual encounter surveys (were recorded. The first author (WS) first visited Southport during a family vacation in 1986. In 1988, a family holiday home was built in Southport and visits became more frequent. From 1988, field notes were taken of all snakes encountered in the area, with additional notes on frogs and lizards. These notes became increasingly detailed in due course and exact date, time and locality were recorded from 1991-2018. In addition, notes pertaining to habitat, refugia, species activity and behaviour were also recorded. Approximately 33 random site visits were made to the area over a 30-year period between 1988 and 2018. The family holiday home was sold in 1998, but shortly thereafter another property was purchased and developed in neighbouring Umtentweni (1998-2003). Dedicated herpetological surveys to Southport continued after 2003 with the last survey conducted in January 2017.

5.3.2 Description of study area

The study area is situated on the south coast of KwaZulu-Natal Province, South Africa. It is demarcated by the Mzimkulu River at Port Shepstone to the south (30°44°S) and the road that intersects the R102 and N2 near Melville in the north (30°39'S), and the N2 dual carriageway (freeway) on the western side and the coastal beach area to the east. The land surface area of the site was ~30 km^2. It encompassed the two main coastal residential villages of Umtentweni and Southport/Bendigo (Figure 5.1).

The study site is within the Indian Ocean Coastal Belt Biome and Bioregion as described in Mucina and Rutherford (2006). The natural vegetation type is a mosaic of KwaZulu-Natal Coastal Belt (CB 3) and Northern Coastal Forest (FOz 7) and associated grasslands (Mucina & Rutherford, 2009). Along the coast, relatively low-density housing in the form of townhouses, houses and small-scale retail complexes, all with gardens, are found. Gardens generally had a high percentage of exotic ornamental plants (WRS pers. obs.). Further

inland, large-scale agriculture in the form of sugarcane *Saccharum spp.* and banana *Musa spp.* plantations are found. There are some fragmented, patches of natural Northern Coastal Forest remaining (Ehlers Smith et al., 2017), but under threat from development (various pers. comm.). Mountain features and large rocky outcrops are largely absent with exposed rock formations mostly confined to the river valleys.

Several perennial east-flowing streams and rivers are found within or adjacent to the study site. The largest is the Mzimkulu River at Port Shepstone which drains into the Indian Ocean. The next river to the north is the Mtentweni River at Umtentweni, then the Mhlangamkulu River at Southport and the Damba River between Bendigo and Melville. The Mhlangamkulu, Damba and Mtwentweni River valleys were surveyed extensively during the duration of this study.

Altitude varies between sea level and 117 m a.s.l. (on the south-west). The climate is sub-tropical with seasonal variation in rainfall and temperature. Mean maximum and minimum temperatures for Port Shepstone are 30.6°C (January) and 8.8°C (July). Mean annual precipitation for the KwaZulu-Natal Coastal Belt is 989 mm, with highest rainfall between the months of October to April (Mucina & Rutherford, 2009).

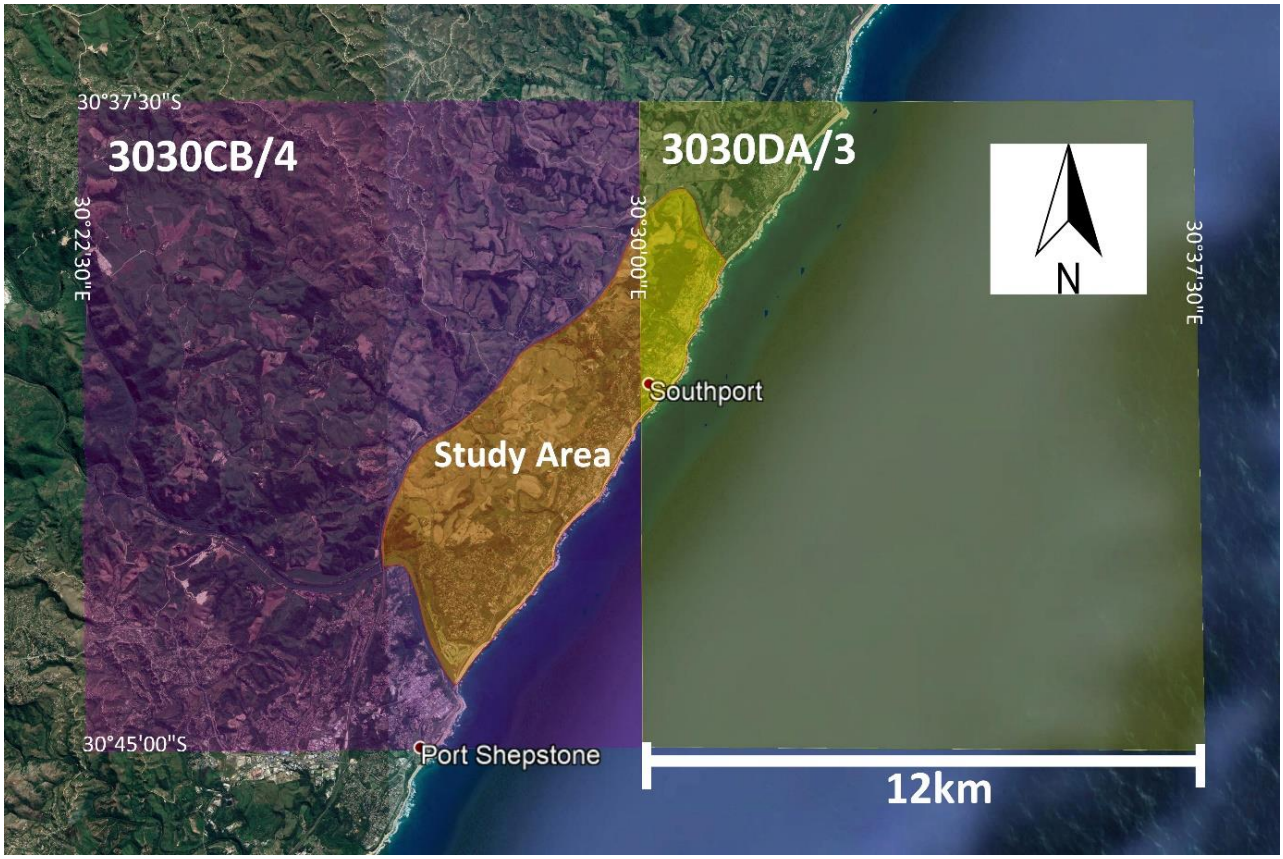

Figure 5.1: Google Earth image showing the area of study within the two adjacent eighth degree grid cells 3030CB/4 and 3030DA/3 in southern coastal KwaZulu-Natal.

5.3.3 Visual encounter surveys

Snakes and amphibians were of primary focus in this study, but the Nile or Water Monitor Lizard *Varanus niloticus* presence was also assessed, as this species has also experienced dramatic decline within the study site (Table 5S.1). The method of surveying for herpetofauna consisted of visual encounter surveys (VES) by systematically searching for actively foraging snakes and lizards. In addition, refugia in the form of building rubble, concrete slabs, wooden boards, fallen logs and building structures were lifted and searched for sheltering reptiles and amphibians. Accumulated leaf litter and compost heaps were also searched. Several records were obtained by a third party when they alerted me to a snake's presence inside a house or garden. No trapping methods were deployed as most species were encountered on public

property or private property where access was granted. Details of locality, date, prevailing weather conditions, activity, refugia and surrounding habitat were recorded when a specimen was obtained.

5.3.4 Evening nocturnal surveys

Evening surveys were carried out in wetlands using a torch to search for amphibians, as well as sleeping chameleons. In addition, night-driving or 'road-cruising' surveys were conducted whereby a vehicle was driven at a slow speed of between 20 and 30 km h^{-1} to search for any active snakes of frogs crossing over the road surface.

5.3.5 Invasive alien plant surveys

During three herpetological surveys carried out on 8 February 2013; 8 November 2014 and 8 August 2015, a simultaneous survey was conducted to record the presence of alien invasive plants in the study site. Identified invasive plants were photographed and georeferenced using a hand-held Garmin global positioning system (GPS) 60 (Garmin, Kansas, USA) for locality points. Notes were taken indicating the type of terrain these plants were found in, i.e., forest, clearings, roadside verges, riverbanks or disturbed land. Estimated density was not recorded, but summary notes were taken of which species were more prevalent than others. Locality points were mapped using the global information systems (GIS) software program QGIS (https://www.qgis.org).

5.3.6 Data collection and processing

Data were collected and recorded in various notebooks and journals by WRS. Individual species records were transferred into a catalogue journal and subsequently entered Excel spreadsheets for ease of extraction. Field notes were originally typewritten and filed. As a

result, event details and survey effort (in hours) could be extracted and calculated. Most species encountered were photographed and a unique field reference number allocated to each record. Several specimens of frogs, lizards and snakes were collected as vouchers and accessioned into the herpetological collection of the Ditsong Museum of Natural History in Pretoria (formerly the Transvaal Museum). This was particularly the case with road-killed specimens. Museum accession numbers are given in the individual species accounts (Table 5S.1).

A species checklist was compiled for all species expected to occur within the study site. Historical distribution data were obtained from Bourquin (2004), Minter et al. (2004) and Bates et al. (2014). Presence /absence data were analysed using descriptive statistics. During subsequent surveys, a perceived decline in snakes (and a few other species) was observed. To test this statistically, all survey hours were calculated and divided into three equal subsets. Random snake encounters (records of snakes encountered by chance during routine maintenance work, gardening or called to attention by a third party) are each taken as one survey hour. Using data from field records, actual survey effort in hours was extracted and calculated and the number of snakes recorded during each survey added. All snake records were combined to remove bias in analyses based on species traits, i.e. skewed detection probability because of cryptic species. For example, South-eastern Savanna Vine Snakes *Thelotornis capensis* are undoubtedly much more common but because of their cryptic and arboreal nature, are relatively difficult to detect using visual encounter survey methods. As a result, indicated declines in encounter rates were not confined to any one species, but taken across all 108 records and 21 species encountered. The current data set was too limited to infer species specific declines. Survey hours were also matched against seasons to avoid bias due to fluctuating activity with reptiles between the drier and cooler winter period and the wetter and warmer summer season. Simple descriptive statistics and correlations were conducted with Statistica (Statsoft, Tulsa, OK).

5.4 RESULTS

5.4.1 Species composition

A total 248 days (or 33 site visits) were spent in or adjacent to the survey site between 1988 and 2018. However, actual survey effort in hours totalled 327 h. This was divided into three equal units totalling 109 h. This figure was then adjusted slightly to fit into three defined periods: Period 1 = 120 h (1988-1994/7 years); Period 2 = 102 h (1995-2001/7 years) and Period 3 = 105 h (2002-2018/16 years) (Figure 5.2). The greater duration in Period 3 was the result of less frequent visits to the study site over a longer period. Survey effort in hours was found to be relatively stable between seasons so as not to influence the outcome (Figure 5.2).

A total of 45 species were found (totalling 76 amphibian, 60 lizard and 108 snake records (Table 5.1). From these a total of 14 frog, 10 lizard and 21 snake species were recorded from the study site during the 30 years. These, including the number of records, are summarised in Table 5.1 and Table 5S.1. Further details are noted in the individual species accounts (Table 5S.1). The absence of several species can be attributed to unsuitable habitat within the specific areas surveyed, most notably open grassland. Localities of 108 snakes encountered during the survey period in the present study are shown in Figure 5.3.

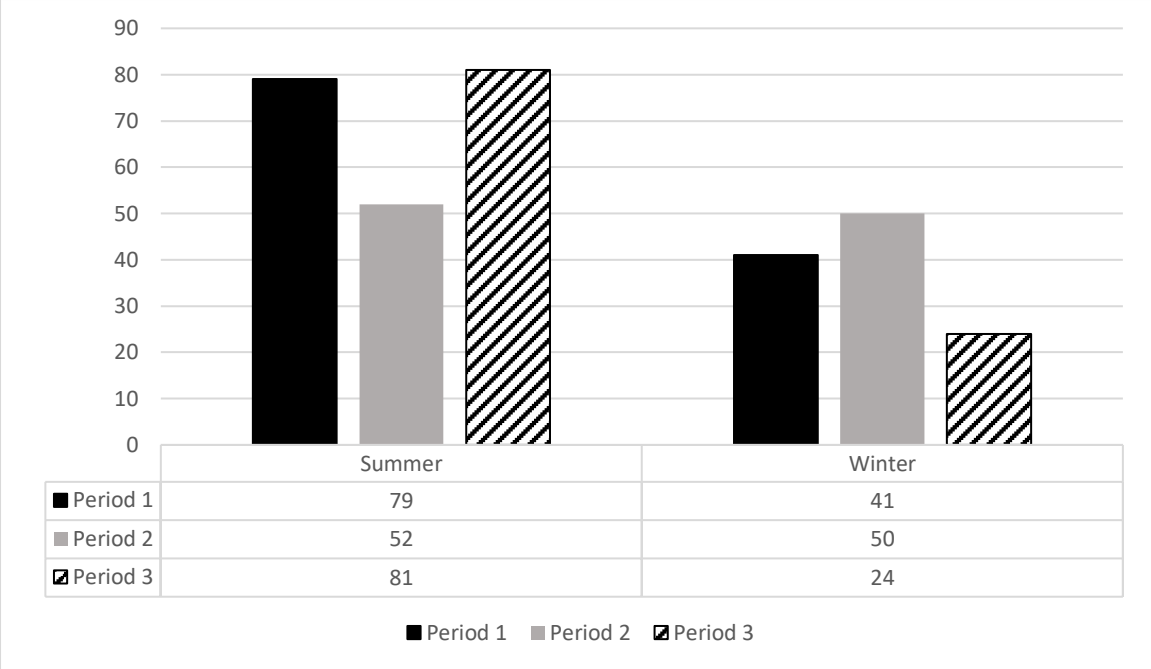

Figure 5.2: Seasonal variation in search effort (in hours) during each consecutive period – summer (October-March) and winter (April to September) during the 30 years.

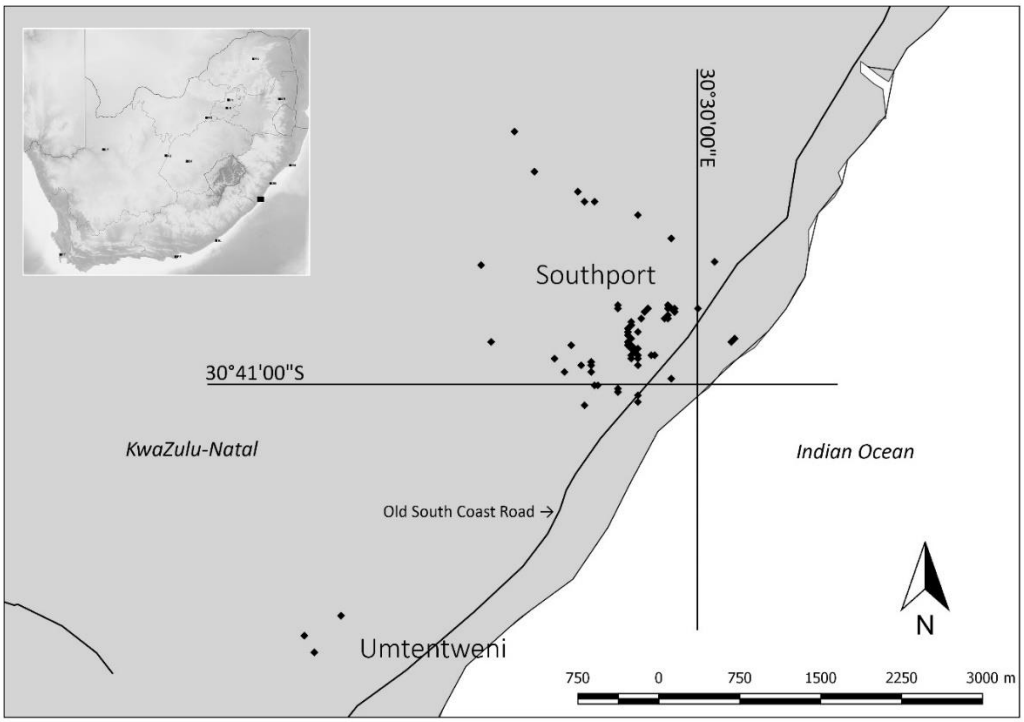

Figure 5.3: Map showing point localities of 108 snakes encountered during the survey period in the present study.

Table 5.1: List of amphibians and reptiles expected to occur within the study site based on distribution data in Bourquin (2004); Minter et al. (2004) and Bates et al. (2014). A ✓ indicates species recorded in the study site as well as the number of records in brackets (one record may represent multiple individuals for frogs and lizards, but for snakes one record = one snake). Species traits indicate dominant activity period and habitat preference.

	Species	**Species traits**	**Recorded in study area**
	AMPHIBIANS		
Family: Pipidae			
1	*Xenopus laevis* (Daudin, 1802) Common Platanna	Diurnal; nocturnal Aquatic	✓ (2)
Family: Bufonidae			
2	*Schismaderma carens* (A. Smith, 1848) Red Toad	Diurnal; nocturnal Terrestrial; wetlands	x
3	*Sclerophrys capensis* Tschudi, 1838 Raucous Toad	Diurnal; nocturnal Terrestrial; wetlands	✓ (16)
4	*Sclerophrys gutturalis* (Power, 1927) Guttural Toad	Diurnal; nocturnal Terrestrial; wetlands	✓ (15)
Family: Brevicipitidae			
5	*Breviceps mossambicus* Peters, 1854 Mozambique Rain Frog	Nocturnal Terrestrial; fossorial	x
6	*Breviceps verrucosus* Rapp, 1842 Plaintive Rain Frog	Nocturnal Terrestrial; fossorial	x
Family: Hyperoliidae			
7	*Afrixalus fornasinii* (Bianconi, 1849) Greater Leaf-folding Frog	Nocturnal Vegetated wetlands	✓ (2)
8	*Afrixalus spinifrons spinifrons* (Cope, 1862) Natal Leaf-folding Frog	Nocturnal Vegetated wetlands	x
9	*Hyperolius marmoratus verrucosus* A. Smith, 1849 Painted Reed Frog	Nocturnal Vegetated wetlands	✓ (5)
10	*Hyperolius poweri* Loveridge, 1938 Power's Long Reed Frog	Nocturnal Vegetated wetlands	x
11	*Hyperolius pusillus* (Cope, 1862) Water Lily Frog	Nocturnal Vegetated wetlands	x
12	*Hyperolius semidiscus* Hewitt, 1927 Yellow-striped Reed Frog	Nocturnal Vegetated wetlands	✓ (4)
13	*Hyperolius tuberilinguis* A. Smith, 1849 Tinker Reed Frog	Nocturnal Vegetated wetlands	x
14	*Kassina senegalensis* (Duméril & Bibron, 1854) Bubbling Kassina	Nocturnal Vegetated wetlands	x
15	*Semnodactylus wealii* (Boulenger, 1882) Rattling Frog	Nocturnal Vegetated wetlands	x
Family: Arthroleptidae			
16	*Arthroleptis wahlbergi* A. Smith, 1849 Bush Squeaker	Nocturnal; diurnal Terrestrial; leaf-litter	✓ (1)

17	*Leptopelis natalensis* (A. Smith, 1849) Natal/Forest Tree Frog	Nocturnal Arboreal	✓ (8)
Family: Ptychadenidae			
18	*Ptychadena oxyrhynchus* (A. Smith, 1849) Sharp-nosed Grass Frog	Nocturnal Terrestrial; wetlands	✓ (4)
19	*Ptychadena porosissima* (Steindachner, 1867) Striped Grass Frog	Nocturnal Terrestrial; wetlands	x
Family: Phrynobatrachidae			
20	*Phrynobatrachus natalensis* (A. Smith, 1849) Snoring Puddle Frog	Nocturnal Rivers; rain-filled ditches	✓ (8)
Family: Pyxicephalidae – Cacosterninae			
21	*Amietia delalandii* (Duméril & Bibron, 1854) Common River Frog	Nocturnal Rivers, streams, dams	✓ (3)
22	*Anyhdrophryne hewitti* FitzSimons, 1947 Natal Chirping Frog	Nocturnal Wet vegetation; streams	✓ (1)
23	*Cacosternum nanum* Boulenger, 1887 Bronze Caco	Diurnal; nocturnal Wet vegetation; streams	✓ (4)
24	*Natalobatrachus bonebergi* Hewitt & Methuen, 1913 Kloof Frog	Nocturnal Wooded streams	x
25	*Strongylopus fasciatus* (A. Smith, 1849) Striped Stream Frog	Nocturnal Rivers; streams; dams	x
26	*Strongylopus grayii* (A. Smith, 1849) Clicking Stream Frog	Nocturnal Rivers, streams; dams	x
27	*Tomopterna natalensis* (A. Smith, 1849) Natal Sand Frog	Nocturnal Rivers; streams; dams	✓ (3)
REPTILIA			
Family: Gekkonidae			
1	*Afroedura pondolia* (Hewitt, 1925) Pondo Flat Gecko	Nocturnal Arboreal; urban buildings	✓ (5)
2	*Hemidactylus mabouia* (Moreau de Jonnes, 1818) Tropical House Gecko	Nocturnal Arboreal; urban buildings	✓ (19)
3	*Lygodactylus capensis* (A. Smith, 1849) Cape Dwarf Gecko	Diurnal Arboreal; urban buildings	✓ (3)
4	*Pachydactylus maculatus* Gray, 1845 Spotted Thick-toed Gecko	Nocturnal Terrestrial	x
Family: Cordylidae			
5	*Chamaesaura anguina anguina* (Linnaeus, 1758) Cape Grass Lizard	Diurnal Terrestrial	x
Family: Gerrhosauridae			
6	*Gerrhosaurus flavigularis* Wiegmann, 1828 Yellow-throated Plated Lizard	Diurnal Terrestrial	✓ (1)
7	*Tetradactylus africanus* (Gray, 1838) Eastern Long-tailed Seps	Diurnal Terrestrial	x
Family: Scincidae			
8	*Acontias poecilus* Bourquin & Lambiris, 1996 Variable Legless Skink	Diurnal Fossorial	x
9	*Panaspis wahlbergii* (A. Smith, 1849) Wahlberg's Snake-eyed Skink	Diurnal Terrestrial	✓ (2)
10	*Trachylepis striata* (Peters, 1844)	Diurnal	x

	Eastern Striped Skink	Terrestrial; semi-arboreal	
11	*Trachylepis varia* (Peters, 1867) Variable Skink	Diurnal Terrestrial	✓ (4)
Family: Varanidae			
12	*Varanus niloticus* (Linnaeus, 1762) Nile/Water Monitor Lizard	Diurnal Terrestrial; semi-aquatic	✓ (5)
Family: Agamidae			
13	*Acanthocercus atricollis* (A. Smith, 1849) Southern Tree Agama	Diurnal Arboreal	✓ (14)
Family: Chamaeleonidae			
14	*Bradypodion melanocephalum* (Gray, 1865) KwaZulu Dwarf Chameleon	Diurnal Arboreal	✓ (3)
15	*Chamaeleo dilepis* Leach, 1819 Common/Flap-neck Chameleon	Diurnal; Arboreal	✓ (4)
Family: Leptotyphlopidae			
1	*Leptotyphlops conjunctus* (Jan, 1861) Jan's Thread Snake	Nocturnal Fossorial	x
2	*Leptotyphlops scutifrons* Peters, 1854) Peter's Thread Snake	Nocturnal Fossorial	✓ (3)
3	*Leptotyphlops sylvicolus* Broadley & Wallach, 1997	Nocturnal Fossorial	X
Family: Typhlopidae			
4	*Afrotyphlops bibronii* (A. Smith, 1846) Bibron's Blind Snake	Nocturnal Fossorial	✓ (20)
Family: Pythonidae			
5	*Python natalensis* A. Smith, 1840 Southern African Python	Nocturnal Terrestrial; semi-arboreal	x
Family: Viperidae			
6	*Bitis arietans arietans* (Merrem, 1820) Puff Adder	Nocturnal; diurnal Terrestrial	✓ (1)
7	*Causus rhombeatus* (Lichtenstein, 1823) Common/Rhombic Night Adder	Diurnal Terrestrial	✓ (8)
Family: Lamprophiidae			
8	*Amblyodipsas concolor* (A. Smith, 1849) KwaZulu-Natal Purple-glossed Snake	Nocturnal Terrestrial; semi-fossorial	x
9	*Amblyodipsas polylepis* (Bocage, 1873) Common Purple-glossed Snake	Nocturnal Terrestrial; semi-fossorial	x
10	*Aparallactus capensis* (A. Smith, 1849) Cape Centipede-eater	Nocturnal Terrestrial	✓ (4)
11	*Macrelaps microlepidotus* (Günther, 1860) Natal Black Snake	Nocturnal; crepuscular Terrestrial	✓ (15)
12	*Atractaspis bibronii* A. Smith, 1849 Bibron's Stiletto Snake	Nocturnal Terrestrial	x
13	*Homoroselaps lacteus* (Linnaeus, 1758) Spotted Harlequin Snake	Nocturnal Terrestrial	x
14	*Boaedon capensis* (Duméril, Bibron & Duméril, 1854) Brown House Snake	Nocturnal Terrestrial	✓ (13)
15	*Limaformosa capensis* (A. Smith, 1847) Common File Snake	Nocturnal Terrestrial	x

16	*Lamprophis aurora* (Linnaeus, 1758) Aurora Snake	Nocturnal Terrestrial	x
17	*Lycodonomorphus inornatus* (Duméril, Bibron & Duméril, 1854) Olive Snake	Diurnal; nocturnal Terrestrial	✓ (3)
18	*Lycodonomorphus laevissimus* (Günther, 1862) Dusky-bellied Water Snake	Diurnal; nocturnal Terrestrial; semi-aquatic	✓ (3)
19	*Lycodonomorphus rufulus* (Lichtenstein, 1823) Common Brown Water Snake	Diurnal; nocturnal Terrestrial; semi-aquatic	✓ (1)
20	*Lycophidion capense capense* (A. Smith, 1831) Cape Wolf Snake	Nocturnal Terrestrial	✓ (1)
21	*Psammophis brevirostris* Peters, 1881 Short-snouted Grass Snake	Diurnal Terrestrial	✓ (3)
22	*Pseudaspis cana* (Linnaeus, 1758) Mole Snake	Diurnal Terrestrial	x
23	*Duberria lutrix* (Linnaeus, 1758) Southern Slug-eater	Diurnal; nocturnal Terrestrial	x
Family: Elapidae			
24	*Dendroaspis angusticeps* (A. Smith, 1849) Eastern Green Mamba	Diurnal Arboreal	✓ (3)
25	*Dendroaspis polylepis* Günther, 1864 Black Mamba	Diurnal Terrestrial; arboreal	✓ (1)
26	*Elapsoidea sundevallii sundevallii* (A. Smith, 1848) Sundevall's Garter Snake	Nocturnal Terrestrial	x
27	*Naja (Afronaja) mossambica* Peters, 1854 Mozambique Spitting Cobra	Diurnal; nocturnal Terrestrial	x
Family: Colubridae			
28	*Crotaphopeltis hotamboeia* (Laurenti, 1768) Herald/Red-lipped Snake	Nocturnal Terrestrial	✓ (14)
29	*Dasypeltis inornata* A. Smith, 1849 Plain Egg-eater	Nocturnal Terrestrial; arboreal	✓ (3)
30	*Dasypeltis scabra* (Linnaeus, 1758) Common Rhombic Egg-eater	Nocturnal Terrestrial; arboreal	x
31	*Dispholidus typus* (A. Smith, 1828) Boomslang	Diurnal Arboreal	✓ (1)
32	*Philothamnus hoplogaster* (Günther, 1863) South-eastern Green Snake	Diurnal Terrestrial; semi-aquatic	✓ (1)
33	*Philothamnus occidentalis* Broadley, 1966 South-western Green Snake	Diurnal Arboreal; terrestrial	✓ (6)
34	*Philothamnus semivariegatus* (A. Smith, 1847) Semi-variegated Green Snake	Diurnal Arboreal	✓ (3)
35	*Thelotornis capensis capensis* A. Smith, 1849 South-eastern Savanna Vine Snake	Diurnal Arboreal	✓ (1)

5.4.2 Snake population declines

In recent years, it was shown that several species of amphibian and reptile had become increasingly rare. These included *Sclerophrys capensis*, *Leptopelis natalensis*, *Varanus niloticus*, *Afroedura pondolia*, *Lycodonomorphus laevissimus* and *Philothamnus occidentalis*. A comparison between snake encounters per hour over the three consecutive periods showed a dramatic decline (Figure 5.4). During Period 1, 65 snakes were encountered (0.54 snakes/h). During Period 2, this dropped by almost 50% to 29 snakes (0.28 snakes/h). In Period 3 a further reduction was recorded at only 14 snakes (0.13 snakes/h). These preliminary data strongly indicated that declines across all species were real and not imagined (Correlation, r = - 0.97). However, due to the small sample size per species, it was not possible to infer which species are being affected.

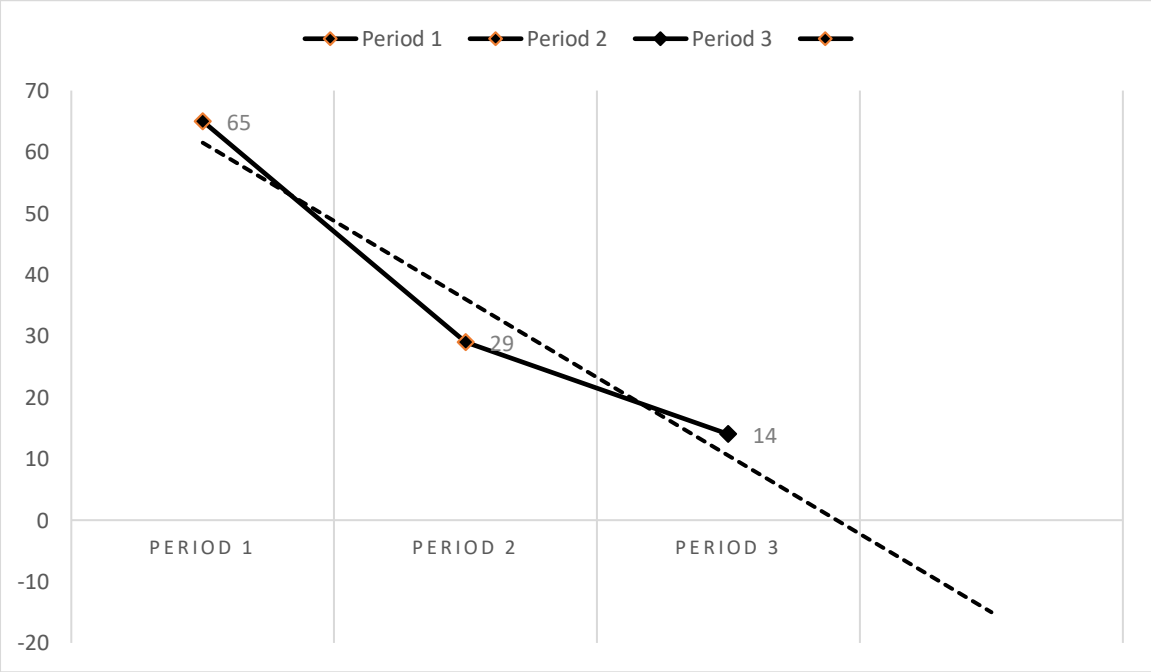

Figure 5.4: Snake declines over three consecutive periods in the present study. (Period 1 = 120 hours/65 snakes (0.54 snakes/h); Period 2 = 102 hours/29 snakes (0.28 snakes/h); Period 3 = 105 hours/14 snakes (0.13 snakes/h)).

5.4.3 Invasive alien plants

A total of 29 species of alien invasive plants were identified during three plant surveys (Table 5.2, Figure 5,5). However, this was an underestimate of true species diversity within the study site (as highlighted by Henderson (2012) in her analysis of alien invasive plants on the South Coast. Further research is needed to sample the density of cover and the direct impact these invasive plants are having on indigenous forest fragments. Certain invasive alien plants are known to leach chemicals into the soil which hinders the growth of competitors. For examples, famine weed (*Parthenium hysterophorus*), pompom weed (*Campuloclinium macrocephalum*) and tree-of-heaven (*Ailanthus altissima*) have been identified as species altering soil chemistry (Henderson, 2001; Richardson & van Wilgen, 2004). The effect of ecological succession and changes in vegetation structure, and the impact in primary herbivores such as insect density and composition, require further investigation. This may have a direct impact on all trophic levels and can directly impact species composition, resulting in declines (Richardson & van Wilgen, 2004; Bellard et al., 2016).

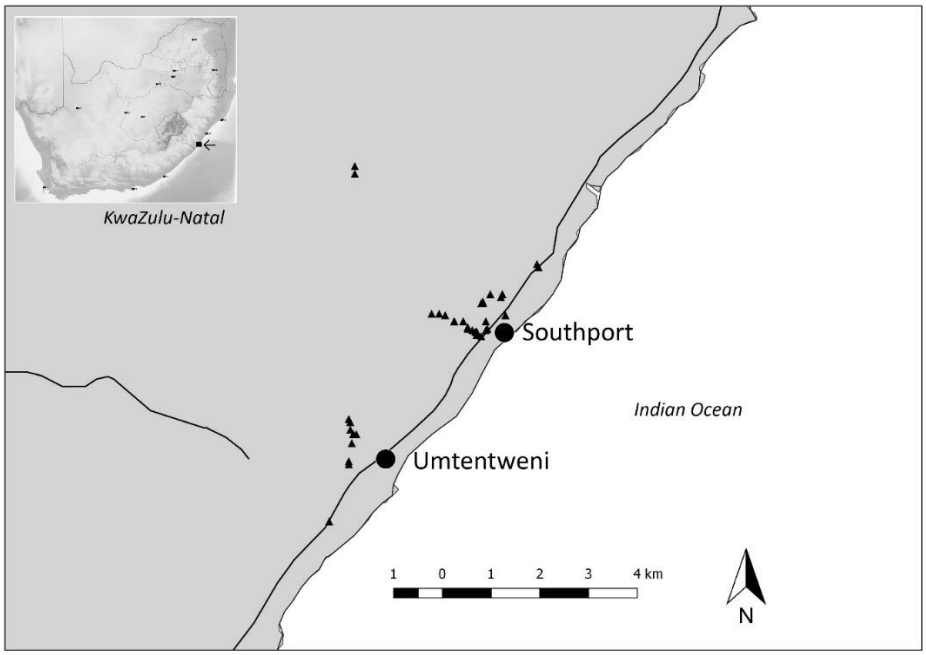

Figure 5.5: Map showing point localities of invasive alien plant surveys within the study site.

Table 5.2: List of alien invasive plants recorded in the study area.

Species	Family	NEMBA Category	Invading
Ageratum conyzoides	Asteraceae	1b	Riverbanks; forest
Alpinia zerumbet	Zingiberaceae	3	Roadsides
Ambrosia artemisiifolia	Asteraceae	Not listed	Riverbanks; pavements
Ardisia crenata	Myrsinaceae	1b	Forest
Canna indica	Cannaceae	1b	Pavements; disturbed ground
Cardiospermum grandiflorum	Sapindaceae	1b	Forest, riverbanks
Casuarina equisetifolia	Casuarinaceae	2	Pavement ornamental
Catharanthus roseus	Apocynaceae	1b	Forest, pavements
Chromolaena odorata	Asteraceae	1b	Open land, forest margins
Fucraea foetida	Agavaceae	1a	Pavements; riverbanks
Grevillea banksii	Proteaceae	1b	Pavements
Hylocereus undatus	Cactaceae	2	Urban gardens
Lantana camara	Verbenaceae	1b	Forest, riverbanks, open ground
Lilium formosanum	Liliaceae	1b	Riverbanks
Melia azedarach	Meliaceae	1b	Riverbanks, pavements
Montanoa hibiscifolia	Asteraceae	1b	Pavements
Nephrolepis sp.	Nephrolepidaceaea	1b	Forest, open ground, pavements
Pennisetum purpureum	Poaceae	2	Riverbanks, pavements
Ricinus communis	Euphorbiaceae	2	Disturbed open ground
Schinus terebinthifolius	Anacardiaceae	1b	Forest, pavements; open ground
Senna didymobotrya	Fabaceae	1b	Riverbanks; disturbed ground
Sesbania punicea	Fabaceae	1b	Riverbanks; open ground
Solanum mauritianum	Solanaceae	1b	Riverbanks; pavements
Sphagneticola trilobata	Asteraceae	1b	Pavements; gardens
Syngonium podophyllum	Aracaceae	1b	Forest, pavements
Tecoma stans	Bignoniaceae	1b	Disturbed open ground
Thevetia peruviana	Apocynaceae	1b	Pavements
Tradescantia zebrina	Commelinaceae	1b	Forest, pavements
Xanthium spinosum	Asteraceae	1b	Riverbanks

5.5 DISCUSSION

Over two decades of data collection in Southport and Umtentwei have highlighted the rich species composition of amphibians and reptiles in this section of the Indian Ocean Coastal Belt. This coastal strip, which extends from Kenya southwards to the Eastern Cape, is considered by many biogeographers and representing a unique biome or vegetational unit (Mucina & Rutherford, 2006). The biome is however highly fragmented by agriculture and urban development and conservation concerns have been highlighted (Eeley et al., 2001). Ehlers Smith et al. (2017) highlighted the conservation value of dense bush clusters in the coastal belt in preserving mammal and bird diversity. They advocate including these dense bush clusters into Protected Area Networks, as they provide important refugia for a multitude of forest-dependent bird and mammal species. The same was found for reptiles and amphibians in the present study. This study is limited in its ability to thoroughly assess which species of reptile or amphibian are more dependent on indigenous forest versus open thicket or scrub. As ectotherms, thermal requirements and refugia selection – both for predator avoidance and thermoregulation, would probably be more important than vegetation structure or composition. However, further research is required to understand how vegetation structure influences ectotherm behaviour, including the influence of predator avoidance. Chameleons (Chamaeleonidae) and green snakes may stand out more in open, drier scrub versus green foliage in forest. This may be why these species are mostly confined to river courses and reed beds in more open country. *Philothamnus semivariegatus* in coastal KwaZulu-Natal are almost always green across the length of their body, whereas those that occupy savanna are green at the forepart but turn bronze-brown towards the rear, allowing them better crypsis in drier savanna. Moisture content of soil and leaf-litter may be an important factor in the presence or absence of fossorial and semi-fossorial amphibians and reptiles, especially the frog *Arthroleptis wahlbergii*, the skink *Acontias poecilus* and perhaps the purple-glossed snake *Amblyodipsas*

concolor. In addition, when assessing species decline, climatic variables must be included in the analysis. However, thermal variables and individual species' preferred temperature range vary considerably. For example, fossorial reptiles may have different thermal requirements to that of arboreal species. Rainfall is another factor which strongly influences reptile activity and therefore will impact in detectability (WRS pers. obs.). For detailed discussion regarding sampling methodology, statistical analysis and practical limitations to inferring and interpreting population data, see Mullin & Seigel (2009). Further details regarding perceived declines is discussed in the individual species accounts in Table 5S.1.

A study by Todd et al. (2017) demonstrated that snakes that feed primarily on vertebrates and use a high proportion of aquatic habitats were more vulnerable to human land use. The extent to which species are threatened by habitat loss varies depending on their life history traits (Todd et al., 2017). A study of Louisina pine snakes (*Pituophis ruthveni*) on the West Gulf Coastal Plain of Texas, USA, demonstrated how a snake population can decline when vegetation structure is altered (Rudolph & Burgdorf, 1997), although conclusions are speculative as the species is rare and secretive making population studies challenging. These pine snakes are strongly associated with pocket gophers (*Geomys breviceps*) on which they predate and utilise their burrows as refugia. Changes in the fire regime have altered the vegetation structure and impacted on pocket gopher populations. It is hypothesised that a decline in pocket gophers precipitate pine snake declines. Similarly, we found declines in the herpetofauna in the present study and it appears to mainly be driven by anthropogenic changing land use. Although fire is not a contributing factor towards snake population declines in the study site, alteration of the vegetation structure could impact on animals' dependent on that type of vegetation and impact detrimentally on trophic or energy flows throughout the system.

Biological invasions are acknowledged as the second largest global threat to biodiversity after habitat destruction. Invasive species in savannas have altered bird diversity,

leading to reduced species richness (Dean et al., 2002). While the impact of alien invasive plants on water resources is well studied, Richardson and van Wilgen (2004) highlighted our lack of understanding on how these plants impact on ecological processes in natural habitats. Changes to vegetation structure and the introduction of invasive plants are known to alter soil chemistry and in turn will impact soil organisms and even leaf-feeding invertebrates. Studies in invasive species have mostly focused on changes to ecosystem properties and less so on functions and processes (Richardson & van Wilgen, 2004). In the present study, we have noted an alarming increase in the composition and diversity of invasive alien vegetation. How, and to what extent, these plants are affecting biodiversity, required further investigation.

Recent studies have examined the mammal and bird composition of fragmented forests and scrub along the lower South Coast of KwaZulu-Natal (Ehlers-Smith et al., 2017). This study provides further information on the composition of amphibians and reptiles within this area, and highlights probably declines in several species. The exact causes of decline cannot be determined; however, it is hypothesised that general degradation in habitat quality may be a contributing factor. Increased diversity and composition of alien invasive plants may be a contributing factor to habitat degradation, but its direct impact on biodiversity needs to be quantified. We advocate further research in this field.

5.6 ACKNOWLEDGEMENTS

WRS would like to thank his parents R. and A. Schmidt, as well as his brothers A., D. and J. Schmidt for assistance during field work. N. Barker and M. Leek are thanked for assistance in the field. The late G. Tomsett is thanked for discussions. The Quroni family are acknowledged for access to their property adjacent to the Mhlangamkulu River. Mrs Fulton is thanked, for updates on snake events in Southport. Mr and Mrs Leek, current residents in Southport, are thanked for their hospitality during recent excursions. R. Ansermino of Shelley Beach is

thanked for discussions. Ezemvelo KZN Wildlife are thanked for their encouragement regarding record keeping and observations. N. Schmidt is thanked for supporting WS during his studies and assisting with snake capture. We are grateful to the University of KwaZulu-Natal and the National Research Foundation (ZA) for funding CTD.

5.7 REFERENCES

Bates, M. F., Branch, W. R., Bauer, A. M., Burger, M., Marais, J., Alexander, G. J., & De Villiers, M. S. (eds). 2014. Atlas and Red List of the Reptiles of South Africa, Lesotho & Swaziland. *Suricata* 1. South African National Biodiversity Institute, Pretoria.

Bellard, C., Genovesi, P. & Jeshke, J. M. 2016. Global patterns in threats to vertebrates by biological invasions. *Proceedings of the Royal Society* B 283: 20152454. http://dx.doi.org/10.1098/rspb.2015.2454

Böhm, M., Collen, B., Baillie, J. E. M., et al. 2013. The conservation status of the world's reptiles. *Biological Conservation* 157: 372-385.

Bourquin, O. 1987. The recent geographical range extension of *Hemidactylus mabouia mabouia*. *Lammergeyer* 38: 12-14.

Bourquin, O. 2004. Reptiles (Reptilia) in KwaZulu-Natal: I – diversity and distribution. *Durban Museum Novitates* 29: 57-103.

Bourquin, O. & Lambiris, A. J. L. 1996. A new species of *Acontias* Cuvier (Sauria: Scincidae) from southeastern KwaZulu-Natal, South Africa. *Annals Transvaal Museum* 36: 223-227.

Branch, W. R. 1998. Field guide to snakes and other reptiles of southern Africa. 399pp. Struik Publishers, Cape Town.

Broadley, D. G. 1984. An atypical specimen of *Acontias plumbeus* from Umtentweni. *Lammergeyer* 32: 52.

Broadley, D. G. 1990. FitzSimons' Snakes of Southern Africa. Jonathan Ball and Ad. Donker Publishers. 387pp.

Bromilow, C. 2010. Problem Plants and Alien Weeds of South Africa. Briza Publications. 424pp. Pretoria.

Dean, W. R. J., Anderson, M. D., Milton, S. J. & Anderson, T. A. 2002. Avian assemblages in native *Acacia* and alien *Prosopis* drainage line woodland in the Kalahari, South Africa. *Journal of Arid Environments* 51: 1-19.

Eeley, H. A. C., Lawes, M. J., & Piper, S. E. 1999. The influence of climate change on the distribution of indigenous forest in KwaZulu-Natal, South Africa. *Journal of Biogeography* 26: 595-617.

Eeley, H. A. C., Lawes, M. J. & Reyers, B. Priority areas for the conservation of subtropical indigenous forest in southern Africa: a case study from KwaZulu-Natal. *Biodiversity and Conservation* 10: 1221-1246.

Ehlers Smith, Y. C., Ehlers Smith, D. A., Ramesh, T. & Downs, C. T. 2017. The importance of microhabitat structure in maintaining forest mammal diversity in a mixed land-use mosaic. *Biodiversity Conservation* doi:10.1007/s10531-017-1360-6.

Ehlers Smith, D. A., Ehlers Smith, Y. C. & Downs, C. T. 2017. Indian Ocean coastal thicket is of high conservation value for preserving taxonomic and functional diversity of forest-

dependent bird communities in a landscape of restricted forest availability. *Forest Ecology and Management* 390: 157-165.

Fitch, H. S. 2006. Ecological succession on a natural area in northeastern Kansas from 1948 to 2006. *Herpetological Conservation and Biology* 1: 1-5.

Gardner, T. A., Barlow, J. & Peres, C. 2007. Paradox, presumption and pitfalls in conservation biology: the importance of habitat change for amphibians and reptiles. *Biological Conservation* 138: 166-179.

Gaston, K. J. & Fuller, R. A. 2007. Commonness, population depletion and conservation biology. *Trends in Ecology and Evolution* 23: 14-19.

Gibbons, J. W., Scott, D. E., Ryan, T. J., Buhlman, K. A., Tuberville, T. D., Metts, B. D., Greene, J. L., Mills, T., Leiden, Y., Poppy, S. & Winne, C. T. 2000. The global decline of reptiles, déjà vu amphibians. *BioScience* 50: 653-666.

Griffiths, C., Day, J. & Picker, M. 2015. Freshwater Life – A field guide to the plants and animals of southern Africa. Struik Nature, Cape Town.

Henderson, L. 2001. Alien Weeds and Invasive Plants. Agricultural Research Council, Pretoria. 300pp.

Henderson. L. (ed). 2012. KZN south coast – biodiversity lost! *SAPIA News* 26, October 2012. Agricultural Research Council & Department of Environmental Affairs, Pretoria.

Hockey, P. A. R., Dean, W. R. J. & Ryan, P. G. (eds). 2005. Roberts – Birds of Southern Africa, VIIth ed. The Trustees of the John Voelcker Bird Book Fund, Cape Town.

Johnson, P. A. & Raw, L. R. G. (1987/1989). The Herpetofauna of sugarcane fields and their environs on the north coast of Natal. Proceedings of the First H.A.A. Conference. *Journal of the Herpetological Association of Africa* 36: 11-18.

Leslie. A. J. & Spotila, J. R. 2001. Alien plant threatens Nile crocodile (*Crocodylus niloticus*) breeding in Lake St Lucia, South Africa. *Biological Conservation* 98: 347-355.

Lindenmayer, D. B., Wood, J.T., McBurney, L., MacGregor, C., Youngentob, K. & Banks, S. C. 2011. How to make a common species rare: a case against conservation complacency. *Biological Conservation* 144: 1663-1672.

McDonald, P. J. & Luck, G. W. 2013. Density of an environmental weed predicts the occurrence of the king brown snake (*Pseudechis australis*) in central Australia. *Herpetological Journal* 23: 161-165.

McCauley, D. J., Keesing, F., Young, T. P., Allan, B. F. & Pringle, R. M. 2006. Indirect effects of large herbivores on snakes in an African savanna. *Ecology* 87: 2657-2663.

Minter, L. R., Burger, M., Harrison, J. A., Braack, H. H., Bishop, P. J. & Kloepfer, D. (eds) 2004. Atlas and Red Data Book of the Frogs of South Africa, Lesotho and Swaziland. SI/MAB Series #9. Smithsonian Institution, Washington, DC.

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

Mullin, S. J. & Seigel, R. A (eds). 2009. Snakes – Ecology and Conservation. Comstock Publishing Associates, Ithaca and London.

Reading, C. J., Luiselli, L. M., Akani, G. C., Bonnet, X., Amori, G. Ballouard, J. M., Filippi, E., Naulleau, G., Pearson, D. & Rugiero, L. 2010. Are snake populations in widespread decline? Biology Letters 6: 777-780.

Richardson, D. M. & van Wilgen, B. W. 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? South African Journal of Science 100: 45-52.

Rudolph, D. C. & Burgdorf, S. J. 1997. Timber rattlesnakes and Louisiana pine snakes of the West Gulf Coastal Plain: hypotheses of decline. *Texas Journal of Science* 49: 111-122.

Schmidt, W. R. 2006. Foraging activity, diet, habitat and defensive behaviour in the Natal Black Snake, *Macrelaps microlepidotus*. *African Herp News* 39: 8-9.

Shih, W-U. & Mabon, L. 2017. Land-use planning as a tool for balancing the scientific and the social in biodiversity and ecosystem services mainstreaming? The case of Durban, South Africa. *Journal of Environmental Planning and Management*, https://doi.org/10.1080/09640568.2017.1394277

Todd, B. D., Nowakowski, A. J., Rose, J. P. & Price, S. J. 2017. Species traits explaining sensitivity of snakes to human land use estimated from citizen science data. *Biological Conservation* 206: 31-36.

WESSA-KZN. 2008. Invasive Alien Plants in KwaZulu-Natal – Management and Control. Wildlife and Environment Society of South Africa, Pietermaritzburg. 124pp.

Supplementary Table 5S.1: Species accounts of all amphibians and reptiles recorded within the study area.

Museum vouchers: TM = Ditsong Museum of Natural History (formerly the Transvaal Museum), Pretoria.

Class: Amphibia

Order: Anura (Salientia)

Family: Pipidae

Xenopus laevis (Daudin, 1802) Common Platanna

No. of records: 2

Although only two records were taken on 31/01/1994 and 29/12/1995 respectively, this species is commonly encountered in rivers, dams, reservoirs and backwaters throughout the study site. None were observed near river outlets close to the ocean where water may be brackish near the beachfront.

Family: Bufonidae

Sclerophrys capensis Tschudi, 1838 Raucous Toad

No. of records: 16

These toads were extremely abundant in Southport and Umtentweni between 1988 to 2001. Thereafter numbers appear to have dropped, but this may be the result of sampling during unfavourable weather conditions. The last toad was recorded on the road on 03/01/2009. They were abundant on our properties in Southport and Umtentweni and often came into the house or sheltered under cement blocks next to the house. Toads in the study site grow relatively large and are attractively and vividly marked in comparison to Raucous Toads observed elsewhere.

Museum vouchers: TM79605; TM79606; TM79607

Sclerophrys gutturalis (Power, 1927) Guttural Toad

No. of records: 15

As with the Raucous Toads above, these toads are common in the study site and occur sympatrically with *Sclerophrys capensis*. They are terrestrial and largely nocturnal, although activity was observed during overcast or rainy weather. Amplexus and breeding was observed in the shallower parts of the Mhlangamkulu River on 9 February 1999.

Museum vouchers: TM79609; TM79610; TM79611

Family: Hyperoliidae

Afrixalus fornasinii (Bianconi, 1849) Greater Leaf-folding Frog

No. of records: 2

Only two records were taken on 09/02/1999 and 23/11/2007. Breeding was observed in November 2007 in thick inundated reedbeds alongside the Mhlangamkulu River. Calls could be heard from a far distance from at least 500m away.

Hyperolius marmoratus verrucosus A. Smith, 1849 Painted Reed Frogs

No. of records: 5

Frogs from the study site are assignable to the subspecies *verrucosus*, although intergrades between *marmoratus* and *verrucosus* are possible. Despite the few documented records, this frog is extremely abundant across the study site. Several hundred were calling in thick reedbeds alongside the Mhlangamkulu River on 23/11/2007. They are tolerant of a wide range of wetlands and commonly found in garden ornamental ponds and water features. Localities appeared to have increased in recent years and recorded from several gardens alongside Berea Road, whereas prior to 2000, they were not noted at this locality.

Hyperolius semidiscus Hewitt, 1927 Yellow-striped Reed Frog
No. of records: 4
One frog was found alive in a boot-print in soft sand on the Damba River on 22/05/1996 with the late Paul Olsen. A second specimen was found in the Mhlangamkulu River on 09/02/1999 and several more were observed and photographed in the same vicinity on 23/11/2007. They appear to favour more open riverside vegetation, and a few were observed in trees between one and two metres above ground level alongside the Mhlangamkulu River.

Family: Arthroleptidae
Arthroleptis wahlbergii A. Smith, 1849 Bush Squeaker
No. of records: 1
Despite only one record, they are however common throughout forested and well-vegetated parts of the study site. The paucity of records is attributable to their extreme cryptic colouration. These are terrestrial frogs which breed in leaf-litter of the forest floor. They are easily identified by their calls during wet, rainy weather and call during the day and evening. However, they are very difficult to locate on the forest floor.

Leptopelis natalensis (A. Smith, 1849) Natal/Forest Tree Frog
No. of records: 8
These charismatic frogs are found along streams and rivers high up in trees and shrubs. During heavy rainfall they will descend to almost ground level and may even be found on the road. They were extremely common in such habitat in Southport, however, field notes taken in 1994 indicate that they had become increasingly rare, especially along the streambed adjacent to our Berea Road property. Nocturnal site visits after 2000 have also indicated that numbers have declined in Southport. Although calls are still frequently heard, the population density, as with *Sclerophrys capensis*, appears to have declined substantially. Further population monitoring is needed across their distribution in order to evaluate perceived declines.

Family: Ptychadenidae
Ptychadena oxyrhynchus (A. Smith, 1849) Sharp-nosed Grass Frog
No. of records: 4
Surprisingly, this frog was not recorded in the study site prior to 2001. Then on 10/10/2001 calls were heard in Umtentweni. Several dozen frogs were subsequently recorded in roadside puddles during rainy weather on 22/11/2007 along a sand road leading off Bendigo Road between Southport and Upper Melville. Another record was taken on 03/01/2009 in Southport. They may be more abundant in inundated grassland and show up on roads during prolonged rainfall. Males were calling on 22/11/2007 from roadside rain-filled depressions with their

bodies submerged in the water. When approached they ducked underneath the water or hopped into nearby vegetation.

Family: Phrynobatrachidae

Phrynobatrachus natalensis (A. Smith, 1849) Snoring Puddle Frog

No. of records: 8

Common along rivers, streams and roadside puddles. The first record was taken on 31/01/1994 in Southport. Outside of the study site at Shelley Beach, they have been observed calling and breeding in stagnant roadside drainage ditches right next to the main road. They appear adaptable to habitat alteration and will use man-made drainage lines for breeding.

Museum vouchers: TM79612; TM81982; TM81983

Family: Pyxicephalidae

Amietia delalandii (Duméril & Bibron, 1854) Common River Frog

No. of records: 3

These frogs are reasonably common in Southport but have only been observed along riverbanks towards the back end of the Damba and Mhlangamkulu Rivers. They don't appear to be as common as in the grassland and savanna biomes (*pers. obs.*). Coastal frogs also appear to be smaller.

Museum voucher: TM79608

Anhydrophryne hewitti FitzSimons, 1947 Natal Chirping Frog

No. of records: 1

Only one specimen found underneath a brick on the lawn on the Berea Road property in Southport. Initially misidentified as a *Cacosternum nanum*, this frog was correctly identified as *Anhydrophryne hewitti* by Dr Elizabeth Scott-Prendini whilst undertaking her PhD research. Presumably more common but other observations may have been mistaken for *Cacosternum*.

Museum voucher: TM79814

Cacosternum nanum Boulenger, 1887 Bronze Caco

No. of records: 4

A common frog in streams and inundated vegetation. A hatchling Brown Water Snake *Lycodonomorphus rufulus* was observed feeding on these frogs in a stream on 25/12/1994.

Museum voucher: TM79596

Tomopterna natalensis (A. Smith, 1849) Natal Sand Frog

No. of records: 3

These frogs are common along sandy and rocky banks of rivers, particularly the upper sections of the Damba River, but not from the Mhlangamkulu River. Easily identified by their calls.

Notes on frog diversity in the study site

27 frog species are estimated to occur within the study site. 14 species (51.85%) were documented. The absence of 13 expected species is likely attributable to lack of suitable habitat or wetlands within the sites surveyed. For example, *Schismaderma carens*, *Breviceps mossambicus*, *Breviceps verrucosus*, *Afrixalus spinifrons spinifrons*, *Kassina senegalensis*, *Semnodactylus wealii*, *Ptychadena porosissima* and *Strongylopus fasciatus* may prefer upland grassland and open pans rather than coastal forest. The Endangered Kloof Frog *Natalobatrachus bonebergi* is most likely absent due to unsuitable habitat. Further sampling may reveal the presence of the reed frogs *Hyperolius poweri*, *H. pusillus* and *H. tuberilinguis* which are known to inhabit lowland coastal forest.

Class: Reptilia

Order: Squamata

Lizards

Family: Gekkonidae

Afroedura pondolia (Hewitt, 1925) Pondo Flat Gecko

No. of records: 5

These geckos were common in Southport between 1988 and 1994, but thereafter became scarce. One record was taken on 20/05/1996 and the last record on 16/10/2001. They were often found inside the house or on building structures or behind loose bark on trees. Despite dedicated searches in recent years, no further specimens have been found. It is speculated that they are being ousted by the larger and more competitive *Hemidactylus mabouia* (Bourquin, 1987; Bates et al., 2014). My data from Southport would concur and given the above observations, further surveys and research are needed to understand the impact *Hemidactylus mabouia 'sensu lato'* is having on *Afroedura pondolia*. Whilst *Hemidactylus* is largely commensal, it is unknown whether they might occupy more isolated boulders and rocky outcrops that provide refugia for *Afroedura*. Pending further research, *Afroedura pondolia* may be of conservation concern as *Hemidactylus* expands across its distribution range. (See also *Hemidactylus mabouia* species account below.)

Hemidactylus mabouia (Moreau de Jonnes, 1818) Tropical House Gecko

No. of records: 19

The taxonomic status of this species is under investigation (Aaron Bauer *pers. comm.*). It is highly commensal, occupying houses and a variety of man-made structures. It is extremely common along the KwaZulu-Natal south coast. Personal field records have recorded this species from Sodwana Bay south through Umhlanga and Durban and as far south as Shelley Beach, Uvongo and Ramsgate where they are abundant. They occur right into the Eastern Cape (Bates et al., 2014). These geckos are spreading at an alarming rate and can occur in high densities. Upward of 30 geckos have been recorded in one hour on buildings at Shelley Beach. Historically, they were only known from far northern KwaZulu-Natal where the first specimens were collected during 1905 at Mseleni in northern Zululand (Bourquin, 1987.) There were no records south of Lake St Lucia prior to 1969. The first specimen from Durban was recorded in 1969 (TM 36084) and in 1979 the species was collected from Warner

Beach (TM 53320) and Park Rynie (TM 53508) (Bourquin, 1987). They appear to be displacing the smaller *Afroedura pondolia* in Southport and may threaten this species throughout their distribution range.
Museum vouchers: TM84288; TM84289

Lygodactylus capensis (A. Smith, 1849) Cape Dwarf Gecko
No. of records: 3
Like *Hemidactylus mabouia* above, this species may also be a recent arrival on the KwaZulu-Natal south coast, although they don't appear to be anywhere near as common. The first record was taken on 26/07/1995 in Southport.

Family: Gerrhosauridae
Gerrhosaurus flavigularis Wiegmann, 1828 Yellow-throated Plated Lizard
No. of records: 1
Only one record of this lizard was taken on 29/12/1995 in Southport. They are abundant on the Gauteng highveld where they occupy open rocky grassland, but also occupy sites with building rubble.

Family: Scincidae
Panaspis wahlbergii (A. Smith, 1849) Wahlberg's Snake-eyed Skink
No. of records: 2
Only two records were taken from Southport, however, the species is fairly common in the area and often seen in roadside leaf-litter and pavements, or under building rubble in open grass. Records from 25/07/1995 and 08/08/2015.

Trachylepis varia (Peters, 1867) Variable Skink
No. of records: 4
A common skink in open coastal bush. They are often seen basking on man-made structures such as walls, benches and concrete slabs. Earlier records from Southport indicated the presence of Red-sided Skinks *Trachylepis homalocephala*. They are provisionally included under *Trachylepis varia*, as they may have been misidentified, as *T. homalocephala* is not known from the KwaZulu-Natal south coast but is recorded from central KZN as well as coastal regions in the Eastern Cape. Further surveys are needed to clarify this.

Family: Varanidae
Varanus niloticus (Linnaeus, 1762) Nile/Water Monitor Lizard
No. of records: 5
This is another species where the number of records doesn't reflect the true historical abundance, as most earlier records were not 'catalogued' as these lizards were seen almost daily and in large numbers. Between April 1986 (first visit to Southport) and 1994, *Varanus niloticus* was abundant along the entire length of the Mhlangamkulu River, especially where the water depth was greater than 1m. They were especially common along a 100m stretch of river where it makes a bend (approximately 2km from the main road bridge). At this site there were stretches of exposed or open riverbanks as well as several large logs overhanging the water, creating ideal basking spots.

On one occasion, at least a dozen adult monitor lizards were counted on these logs and the adjacent riverbank. They were also frequently found away from the river with one caught in our garage at the Berea Road property. After 1994 a noticeable decline was observed, whereby only two or three monitors were seen at any given time. The last record from Southport was taken on 21/05/1996. This is concerning as several dedicated searches along the Mhlangamkulu River have been carried out subsequently with no visual sightings. These surveys were conducted on 10/02/1999; 14/05/1999; 23/11/2007; 08/02/2013 and 08/08/2015. Only three records from the South Coast outside the study site have been taken on 05/01/2010 (Vungu River, Uvongo Nature Reserve); 06/01/2010 in the uMhlanga River at St Michaels and lastly on 02/01/2017 (a road-killed specimen on the R620/Marine Drive near Oslo Beach). I have been told by various South Coast residents that *Varanus niloticus* is hunted extensively for the meat and traditional medicine trades, but I cannot verify this. Observations from the Mhlangamkulu River have shown a reduction in basking sites, with previously open spaces being invaded by elephant grass *Pennisetum purpureum* and other invasive plants. Disturbance by domestic dogs may also be a contributing factor of decline, as several aggressive dogs have been encountered in the same vicinity where the monitors previously occurred. Further research into the thermal, dietary and habitat requirements are urgently needed to evaluate this species in coastal KwaZulu-Natal, as well as the impact of roads and exploitation for protein and traditional medicine.

Family: Agamidae

Acanthocercus atricollis (A. Smith, 1849) Southern Tree Agama

No. of records: 14

This large arboreal agama is common throughout the study area. The first record was taken on 24/07/1995 and the last record on 09/08/2015. They occupy large trees and dead tree stumps. They are frequently seen basking on walls, such as perimeter precast walls. There are few plotted localities along the KwaZulu-Natal south coast in Bourquin (2004) but are however common in the study site.

Museum voucher: TM84297

Family: Chamaeleonidae

Bradypodion melanocephalum (Gray, 1865) KwaZulu Dwarf Chameleon

No. of records: 3

Surprisingly, despite extensive fieldwork and surveys in the area, only three chameleons were found on 09/02/1999 in a reedbed alongside the Mhlangamkulu River. These specimens are referenced in Bourquin (2004) as *Bradypodion* sp. S (near *melanocephalum*) pp. 101. The taxonomic placement of these chameleons is still uncertain but provisionally assigned to *Bradypodion melanocephalum*. Species boundaries and distributions within *Bradypodion* in KwaZulu-Natal are still not fully understood and it is suspected that a degree of hybridisation occurs between closely related species. Branch (1998) mentions *Bradypodion caffer* (as *B. caffrum*) as occurring as an isolated population in Oribi Gorge, however, these records are not shown or discussed in subsequent reviews of Bourquin (2004); Tolley & Burger (2007) and Bates et al. (2014). Bourquin highlights a *Bradypodion* sp. P (near *caffrum*) from Umtamvuna Nature Reserve. Clearly further research is needed to assess diversity, distribution and composition of *Bradypodion* on the south coast of KwaZulu-Natal. One of the Southport chameleons gave birth to several young.

Museum vouchers: TM82886; TM82962; TM82963; TM82964

Chamaeleo dilepis Leach, 1819 Common/Flap-neck Chameleon
No. of records: 4
Only four records of *Chamaeleo dilepis* were taken from Southport and all during December 1995.

Notes on lizard diversity within the study site

Lizard diversity along the KwaZulu-Natal south coast is rather poor compared with snakes. Only 15 species are predicted to occur within the study area and 10 species (66.66%) were recorded. *Trachylepis striata* is likely to occur within the area as it has been recorded further south at Shelley Beach (WRS unpublished data). *Pachydactylus maculatus*, *Chamaesaura anguina anguina* and *Tetradactylus africanus* are grassland specialists which explains their absence in the sites surveyed which are either dense bush, coastal forest or riverine bush. Of interest is the limbless fossorial skink *Acontias poecilus* which is listed as Endangered. The first specimen was collected on 26 February 1981 at Umtentweni and identified as an atypical *Acontias plumbeus* (Broadley, 1984). It was subsequently described by Bourquin and Lambiris as *Acontias poecilus* in 1996, based on further specimens. The holotype is an adult female from Leisure Bay and two paratypes, including Broadley's atypical *A. plumbeus* are from Umtentweni (TM55954 and TM79314). Despite extensive searching in suitable habitat, including raking of leaves and opening up compost heaps and accumulated vegetation mounds, this species was never detected in either Southport or Umtentweni.

Snakes

Family: Leptotyphlopidae

Leptotyphlops scutifrons (Peters, 1854) Peter's Thread Snake
No. of records: 3
Three records were taken on 04/07/1992; 24/07/1995 and 22/05/1996. Interestingly, all are from the drier winter season. They were all found under rocks or building rubble resting on soil. All three are assigned to *Leptotyphlops scutifrons*, but field identification of thread snakes is notoriously difficult, and another species cannot be ruled out.

Family: Typhlopidae

Afrotyphlops bibronii (A. Smith, 1846) Bibron's Blind Snake
No. of records: 20
These fossorial blind snakes are very common in the area. Most specimens were found in a small area of approximately 2m x 6m alongside Berea Road adjacent to a nursery. They were easily found by lifting cement blocks lying on loose soil. The first specimens were found at this site on 06/07/1992 and the last one recorded here on 23/11/2007. Another snake was found on the road at 21h11 in the evening on 03/01/2009.
Museum vouchers: TM79815; TM80407; TM84035

Family: Viperidae

Bitis arietans arietans (Merrem, 1820) Puff Adder

No. of records: 1

Only one large adult was found as a road-kill on a sand road in forested habitat adjacent to the Umhlangamkulu River in December 1988.

Causus rhombeatus (Lichtenstein, 1823) Common/Rhombic Night Adder

No. of records: 8

This is a common snake in the study area and along the KwaZulu-Natal coast in general. Despite its common name, all eight specimens were actively foraging during the day. A very large snake exceeding 1m in length was killed while mowing the lawn on the Berea Road property. On 26/12/1996 at 13h10 another night adder was observed hunting a toad *Sclerophrys sp.* on the property. Three adult gravid females were collected during December 1991 and all laid egg clutches on 26 December 1991. Approximately 40 eggs were artificially incubated and hatched on 9 March 1992 after an incubation period of 74 days. This may be the only record of synchronous egg deposition in the species. As the snakes were kept together, clutch sizes, egg mass and other meristic data were not recorded.

Family: Lamprophiidae

Aparallactus capensis (A. Smith, 1849) Cape Centipede-eater

No. of records: 4

Four snakes were recorded. One was found in a compost mound on the Berea Road property. Another was found swimming across the river during the day. A third snake was discovered under building rubble next to the Bendigo Nature Reserve and the fourth specimen was found at night on the road on 03/01/2009 at 21h00.

Macrelaps microlepidotus (Günther, 1860) Natal Black Snake

No. of records: 15

This terrestrial and semi-fossorial snake appears to be relatively common in the study site. They are nocturnal and crepuscular with at least three individuals found actively foraging in the early morning (06h00; 06h30 and 08h50 respectively). They are frequently found on the road at night, especially during rainy weather. Others have been found inside rotting logs and under accumulated leaf debris. These snakes are listed as Near Threatened (Bates et al., 2014). In Kloof near Durban, they have been found in urban areas (WRS unpublished data). A gravid female was found in December 1991 and another snake held captive fed on a Cape Skink *Trachylepis capensis*, two small river frogs *Amietia delalandii* and five small weaner laboratory mice *Mus musculus* during a single feeding session. Further data can be viewed in Schmidt (2006). These snakes can easily be differentiated from the superficially similar-looking purple-glossed snakes (*Amblyodipsas*) by the single subcaudal scales versus paired subcaudals in *Amblyodipsas*.

Boaedon capensis (Duméril, Bibron & Duméril, 1854) Common Brown House Snake

No. of records: 13

These beautiful non-venomous constrictors are common in the study site. They are nocturnal and shelter under rocks, logs or building rubble during the day. Snakes from coastal KwaZulu-Natal are particularly attractive, being

dark brown with vivid pale stripes running along the flanks up to two-thirds of the body length. They are also known to exceed 1m in length in this area. Five snakes were DOR (dead-on-road).
Museum voucher: TM79813

Lycodonomorphus inornatus (Duméril, Bibron & Duméril, 1854) Olive Snake
No. of records: 3
Previously known as the Olive House Snake (*Lamprophis inornatus*), genetic studies have demonstrated a closer affinity to the water snakes *Lycodonomorphus*. A road-killed adult snake was found on Berea Road in December 1990. A juvenile snake was found as a road-kill in Yellowwood Road by Anthony Schmidt in December 1990. A third snake was observed swimming across the Mtentweni River at 12h17 on 08/11/2014.

Lycodonomorphus laevissimus (Günther, 1862) Dusky-bellied Water Snake
No. of records: 3
Records of this species from Southport are somewhat of an enigma. The late Graham Tomsett collected several specimens in the Mhlangamkulu River between 1988 and 1992. Yet despite extensive searches no specimens could be found by WRS. Then in the afternoon of 10/02/1999, three specimens were found in short duration along the upper section of river in forest. Two were caught while swimming in shallow water and a third melanistic snake was found underneath a rock half submerged in water. Subsequent dedicated searches have failed to locate further specimens.

Lycodonomorphus rufulus (Lichtenstein, 1823) Common Brown Water Snake
No. of records: 1
Presumably much more common in the area than indicated, as they can be abundant elsewhere. Only one juvenile snake was found in the evening on 25/12/1994 while hunting *Cacosternum nanum* in a small stream next to Yellowwood Road.

Lycophidion capense capense (A. Smith, 1831) Cape Wolf Snake
No. of records: 1
Only one snakes was recorded on the road in the evening on 22/11/2007 at 21h54.

Psammophis brevirostris Peters, 1881 Short-snouted Grass Snake
No. of records: 3
These snakes are common in grassland and open thickets in KwaZulu-Natal but scarce in coastal forest. The three specimens observed were seen in open clearings – a sand road bordered by scrub; sand bank bordered by grass next to the river and another in open grassland.

Family: Elapidae
Dendroaspis angusticeps (A. Smith, 1849) Eastern Green Mamba
No. of records: 3

The Eastern Green Mamba is listed as Vulnerable due to ongoing habitat destruction and a fragmented population. Three snakes are recorded from Southport. Two snakes were caught in coastal milkwood trees on the Southport beachfront, one in December 1990 and the second snake caught on 08/02/1994. A third green mamba was seen crossing the road in Southport on 28/12/1995. A skinned green mamba was inspected in a workshop at a house on Berea Road on 05/07/1992. The snake had apparently been killed in the garden. A green mamba shed skin was found by Dean Schmidt in the Bendigo Nature Reserve on 06/07/1992. Given the fragmented population along the KwaZulu-Natal coast and ongoing habitat destruction, ecological studies into this snake's behaviour, reproduction, dietary and habitat requirements, persecution and home ranges are needed to formulate a long-term conservation management plan for this species. Genetic isolation is of primary concern, so population structure and habitat corridors are essential focus areas. They can adapt and navigate through dense bush and these areas must feature in Protected Area Networks as highlighted by Ehlers Smith et al., 2017.

Dendroaspis polylepis Günther, 1864 Black Mamba
No. of records: 1
This large, highly venomous elapid is common in peri-urban settings on the outskirts of Durban (Nick Evans *pers. comm.*). Only one juvenile snake was seen in Southport during December 1988. It had taken shelter underneath a small inflatable rubber boat and when lifted the property owner killed the snake by throwing a side-cutter onto its head. A lack of further records may be attributable to the coastal forests in the area, as these snakes prefer more open country and valley bushveld thickets.

Family: Colubridae
Crotaphopeltis hotamboeia (Laurenti, 1768) Red-lipped/Herald Snake
No. of records: 14
This snake is common in the study site. One found at the nursery on Berea Road had white lips instead of red, which is not uncommon in KwaZulu-Natal snakes. They are nocturnal and during the day shelter under logs, boards, metal sheets and cement blocks. According to Eskom and municipal employees, they are often found inside electrical and water meter boxes. The voucher from Umtentweni was killed in such manner.
Museum vouchers: TM84291; TM84032

Dasypeltis inornata A. Smith, 1849 Plain/Southern Brown Egg-eater
No. of records: 3
These snakes are nocturnal but probably common in coastal forest and thickets. An adult snake was found on the sand road next to the Umhlangamkulu River at night on 26/07/1995. A road-killed specimen, collected as a voucher, was found on 27/12/1995. A third snake was found on the road on 07/01/2015 at 21h57.
Museum voucher: TM80122

Dispholidus typus (A. Smith, 1828) Boomslang
No. of records: 1

Only one snake was positively identified as it quickly ascended trees near the Umhlangamkulu River. It was a brown phase individual and possibly female based on colour. A second snake may have been observed by Anthony Schmidt who also observed a large brown snake in trees.

Philothamnus hoplogaster (Günther, 1863) South-eastern Green Snake
No. of records: 1
These snakes are apparently common in coastal bush, but only one snake was positively identified in bushes alongside the stream on the Berea Road property in December 1990.

Philothamnus occidentalis Broadley, 1966 South-western Green Snake
No. of records: 6
A common snake in coastal forest, although numbers appear to have declined. However, they are still regularly seen in Southport (Mr T. Leek *pers. comm*.). These snakes are often seen crossing the road. An adult road-killed male and female were found together during August 1988 and photographed. An adult was caught in the neighbour's house on 30/12/1995. Another snake was crossing the riverbed on 06/04/1992. These snakes feed on lizards, geckos and frogs and often shelter behind man-made structures like wall signs and inside gate posts. Further research is needed to determine if numbers are declining.

Philothamnus semivariegatus (A. Smith, 1847) Semi-variegated Green Snake
No. of records: 3
This snake is very common around Durban (Nick Evans and Tyrone Ping *pers.comm*) but only three records were taken in Southport. However, they are arboreal and cryptically coloured therefore many may go undetected. The numbers from Durban are mostly from snake removals inside houses or on properties, but physically searching for these snakes can be challenging. A road-killed snake was collected on 31/12/1995.
Museum voucher: TM80115

Thelotornis capensis capensis A. Smith, 1849 South-eastern Savanna Vine Snake
No. of records: 1
This is the most cryptic species of African snake, so detection in forest and thickets is very difficult. Therefore, they are likely to be much more common than current records suggest. The only snake observed in Southport was found crossing over Berea Road on 01/01/2009. It was photographed and released.

Notes on snake diversity within the study site

A total of 35 snake species are predicted to occur within the study site. 21 species (60%) were recorded during this study totalling 108 individual snakes. *Python natalensis* may occur within the study site as a healthy population is known from Oribi Gorge Nature Reserve. Two purple-glossed snakes should occur in the area: *Amblyodipsas concolor* and *Amblyodipsas polylepis*. They share very similar behavioural and habitat traits to the Natal Black Snake and competition for resources may explain their absence in the area, although in other parts of their range in KwaZulu-Natal these species are sympatric (Bourquin, 2004; Bates et al., 2014). Further surveys, especially by employing trapping methods using drift fences and pitfall traps may reveal the presence of these

species in the area, including *Atractaspis bibronii*. The Cape file snake *Limaformosa capensis* is expected to occur in the study site but remains undetected. The absence of *Pseudaspis cana* is probably due to unsuitable habitat, although they are apparently common in some northern KZN coastal regions (Jens Reissig *pers. comm.*). Another notable snake that was not detected is Sundevall's Garter Snake *Elapsoidea sundevallii sundevallii*, a semi-fossorial elapid which should occur in the study site.

CHAPTER 6

Peri-urban rinkhals *Hemachatus haemachatus* (Reptilia: Squamata: Elapidae) in Gauteng: Adapting to a changing landscape

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Formatted as a manuscript for submission to an international peer review journal

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Running header: Peri-urban rinkhals

6.1 ABSTRACT

The rinkhals (*Hemachatus haemachatus*) is a near-endemic elapid snake in southern Africa. Populations appear to be declining in some regions such as the Western Cape Province and eastern Zimbabwe, yet these snakes are thriving in Gauteng, South Africa's smallest and most densely populated province. This study examined a population of peri-urban rinkhals in a rapidly transforming landscape in the Ekurhuleni and northern Johannesburg municipal

districts. 330 records extracted from two private databases were analysed and ecological attributes contributing to the success of these snakes within a peri-urban environment are discussed. We predict that the success of these snakes is strongly correlated to sustained amphibian occurrence, which constitutes over 80% of their diet, and that the environment in central-eastern Gauteng, is conducive to the success of amphibian reproduction, particularly toads (Bufonidae), which is sustaining a thriving population of rinkhals.

Key words: urbanisation, snakes, conservation, urban exploiter

6.2 INTRODUCTION

Reptiles, and snakes, are attracting increased conservation scrutiny as a result of reported population declines (Rudolph & Burgdorf, 1997; Gibbons et al., 2000; Reading et al., 2010; Clark et al., 2011). As a result, there is increasing interest in population structure, population trends and snake communities (i.e. Martins et al., 2008; Ernst et al., 2017). However, the generally cryptic and secretive nature of snakes makes them one of the most challenging and difficult of all vertebrate taxa to study in terms of population trends (Reading et al., 2010; Steen, 2010). Few, if any, long-term population studies on snakes have been undertaken in South Africa. As a result, inferences of population trends are largely anecdotal and based on 'general consensus' between herpetologists and conservationists based on personal field experience. These data are supplemented with museum data, and more recently, data supplied through virtual museums (i.e. citizen science projects), such as the Southern African Reptile Conservation Assessment, which lead to the publication of the Atlas and Red List of the Reptiles of South Africa, Lesotho and Swaziland (Bates et al., 2014). The results in turn were submitted to the IUCN and incorporated into updated Red List assessments (https://www.iucnredlist.org). One of the criteria of the IUCN Red List, which is used to inform global conservation priorities, is to determine population trends. However, in the absence of

robust field surveying and population monitoring over extended periods of time, the use of anecdotal observations may hold value in providing baseline data on population dynamics. Limited capacity, accessibility, logistical constraints and the lack of continuity after initial surveys are likely to continue, hindering efforts to gain insightful data on population trends, especially with difficult to observe groups such as snakes. This study provides baseline data on a population of rinkhals (*Hemachatus haemachatus*) in central-eastern Gauteng Province in South Africa and highlights the challenges and limitations in snake population ecological studies, whilst suggesting possible options in order to gain more insight into snake populations, which are essential criteria in determining the conservation status of snakes and informing future conservation initiatives.

The rinkhals is a medium-sized elapid snake distantly related to the true cobras (*Naja*). They differ from the latter by their keeled dorsal scales, absence of solid teeth on the maxilla and by producing live young rather than laying eggs as in the genus *Naja.* (FitzSimons, 1962; Broadley, 1990; Branch, 1998). In South Africa, rinkhals are distributed from the Western Cape eastward through the Eastern Cape, KwaZulu-Natal, Free State Provinces and grassland regions of Gauteng, Mpumalanga and North West Provinces. It also occurs in north-western Lesotho and eastern Swaziland. A relict population is known from the Nyanga highlands of eastern Zimbabwe (Broadley, 1990; Branch, 1998; Alexander, 2014). A record from Charre, Mozambique on the Zambezi River (Cott, 1936) is likely erroneous as it is unlikely habitat for this species, being savanna and at low altitude. Likewise, no further specimens have been recorded from Mozambique in the intervening years. Historical records of rinkhals in in the far north-western Western Cape (Sutherland and Beaufort West) as well as Kimberley in the Northern Cape (plotted by FitzSimons, 1962 and Broadley, 1983; 1990) have not been corroborated by further museum records or sightings. Further surveys are needed to determine

if these were natural populations and if they have subsequently been extirpated from these localities.

Anecdotal observations from around Cape Town in the Western Cape suggest that rinkhals populations have declined (Smith, 2011). In addition, despite several concentrated survey efforts, the population from eastern Zimbabwe appears to be extinct (Broadley, 2018). In contrast, populations from central and eastern Gauteng appear to be thriving despite intensive anthropogenic land-use change for small-scale agriculture and sustained urban development over the preceding decades. They are notably common in peri-urban landscapes, such as agricultural smallholdings in central and eastern Gauteng Province. This study examined the occurrence, ecological attributes and species traits that may be contributing towards their success in Gauteng.

6.3 METHODS

6.3.1 Description of study area

The study area encompassed approximately 1 700 km² situated in the central-eastern section of Gauteng Province, South Africa. Altitude here varies between an elevation of 1 400 - 1 760 m. The area is a mixed land-use region ranging between high-density urban development to peri-urban agricultural small-holdings and larger tracts of agricultural farmland, mostly to produce maize (*Zea mays*), and for livestock grazing. Historically, the area has seen much mining activity with several gold mines distributed across the East Rand (Germiston, Benoni and Springs) (Appelgryn, 1984). It is also an area of high-density manufacturing with numerous mega-industrial developments.

Natural vegetation remains in fragmented and scattered areas throughout, ranging in size from a few to several hundred hectares in extent. The study area falls within the Grassland Biome and Mesic Highveld Grassland Bioregion (Mucina & Rutherford, 2006). The five main

grassland units include Soweto Highveld Grassland, Egoli Granite Grassland, Carletonville Dolomite Grassland, Tsakane Clay Grassland and Eastern Highveld Grassland (Mucina & Rutherford, 2006). Indigenous trees are conspicuously absent from these grasslands with small to medium-height shrubs mostly confined to rocky outcrops and valleys. There are, however, numerous dense stands of exotic *Eucalyptus* and Australian wattles *Acacia mearnsii*, *A. decurrens* and *A. dealbata*. Several other invasive alien trees, including *Robinia pseudoacacia*, *Ailanthus altissima* and *Melia azedarach*, are increasing in range and density (WRS pers. obs.). Frequent annual fires are a feature of this landscape and many winter grassland fires are man-made.

The climate is characterised by a warm summer with rainfall and a dry, cold winter. Mean annual precipitation ranges between 662 mm and 726 mm. Frost occasionally occurs in winter (Mucina & Rutherford, 2006). Hydrological features include numerous small perennial and annual streams and small rivers. The area has numerous pans and man-made dams. Large rivers and natural dams and lakes are absent, but some areas contain large reedbeds in wetland areas and seepage zones.

6.3.2 Data collection

This study focused on a specified region in central and eastern Gauteng where rinkhals are still abundant. Data records were obtained primarily from random Visual Encounter Surveys (VES) and problem snake removals by permitted snake catchers spanning a period of 30 years (1988-2018) and collated by WRS and CP. Generally problem snakes were released as close to the capture site as reasonably possible (i.e. nearest open veld). Snakes were not marked or inserted with passive integrated transponder (PIT) tags, therefore it is not known whether two or more records corresponded to the same individual snake. However, based on the widespread

localities and size differences between captures, the authors believe that this was highly unlikely and that all 330 records represent individual specimens.

6.3.3 Data analyses

All rinkhals data obtained were formatted and entered into the global information systems (GIS) software program QGIS (https://www.qgis.org) to generate a distribution map, as well as a vegetation overlay. Using the analytical tools in the software, records were sampled to determine which natural grassland types records corresponded with presence. Vegetation units used were as described in Mucina and Rutherford (2006). It must be highlighted however, that much of the natural grassland has been transformed by anthropogenic land use change (agriculture, housing and infrastructure development) or plant community succession (invasive grasses) where records do exist, therefore the vegetation type may not reflect the true vegetation structure in the altered landscape. Distribution of records within the grassland vegetation units are random and do not necessarily reflect any ecological preference by rinkhals to these vegetation types. WRS mostly obtained records from the Midrand/Kempton region and CP mostly obtained records from Kempton Park, Benoni and the eastern East Rand. There is, however, an overlap between the two data sets.

Several rinkhals species traits were examined in order to understand what factors were contributing to their success in the study area. Historical data were obtained from the literature and Museum collections. These included mean adult size; diet; reproduction and fecundity; foraging activity and habitat preferences. These traits were compared with the two populations which appear to have experienced dramatic declines, i.e. the Cape Town and Inyanga populations (Smith, 2011).

6.4 RESULTS

Two data sets (WRS and CP respectively) were combined for the analyses and combined to include a total of 330 rinkhals records spanning 30 years (1988-2018) in the central-eastern section of Gauteng Province. These records showed that rinkhals still maintain viable populations within the study area and appear to be relatively abundant (Figure 6.1). Approximately 290 records were taken between 2010 and 2018. Seasonal activity corresponded strongly to the summer rainfall season. The highest number of records (71) were taken in January.

The highest number of rinkhals records were obtained in Soweto Highveld Grassland (n = 241), followed by Egoli Granite Grassland (n = 39); Tsakane Clay Grassland (n = 17); Carletonville Dolomite Grassland (n = 16) and Eastern Highveld Grassland (n = 13). This reflected where WRS and CP are primarily based and have responded to callouts rather than demonstrating a specific habitat preference utilised by rinkhals. In addition, much of the natural vegetation (veld structure and natural plant composition) may have been altered at localities from where snakes were encountered.

Simple descriptive statistics and correlations were conducted with Statistica (Statsoft, Tulsa, OK).

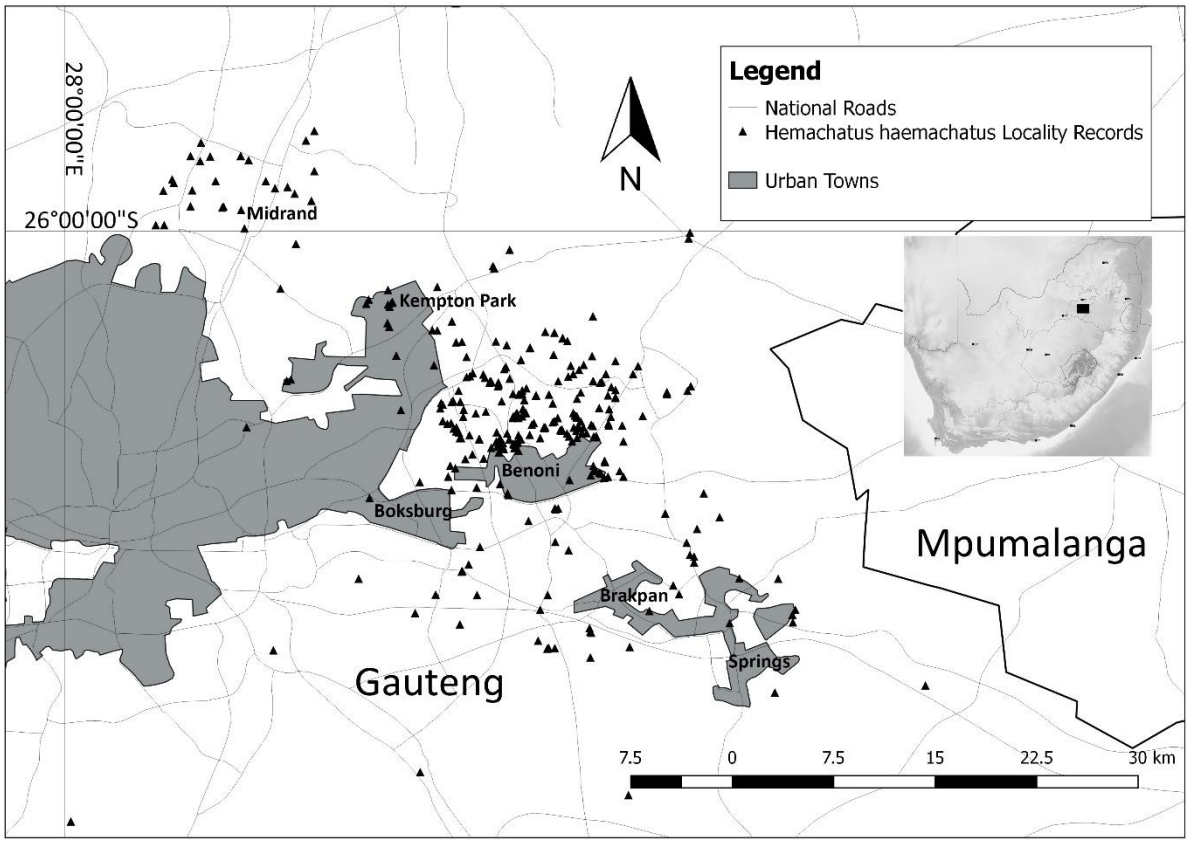

Figure 6.1: Localities for the rinkhals *Hemachatus haemachatus* in central-eastern Gauteng, South Africa, obtained in the present study.

6.4.1 Lifestyle traits

Body size- Historical data for rinkhals body size were as follows: FitzSimons (1962) gave the longest rinkhals length as: female from Johannesburg (TM5694) s-v: 1039 mm + t: 196 mm = TL: 1235 mm. De Waal (1978) gave the longest lengths as: male (BM2615) from Karreepoort, Free State s-v: 1075 mm + t: 235 mm = TL: 1310 mm and a female (BM2614) also from Karreepoort, Free State as s-v: 1152 mm + t: 213 mm = TL: 1365 mm. Jacobsen (1989) recorded the following lengths: largest male: 1 140 mm (N5843 from Wolmaranstad); largest female: 1 022 mm (snout-vent length) from Palmietfontein. He gave the mean male snout-vent length of 685 mm (n = 12) and for females – 692 mm (n = 6).

The largest male measured by the authors (WRS R-00776 from Glen Erasmia, Kempton Park) measured s-v: 950 mm + t: 80 mm =TL: 1 030 mm. The largest female (WRS R-00597 from Bredell, Kempton Park) measured s-v: 610 mm +t: 130 mm = TL: 740 mm). However, a larger male was measured by CP totalling 1 420 mm in length. This may be the largest male yet measured. There appears to be no significant size differentiation between adult males and females *(in lit.).* The mean adult size was 700 – 1300 mm making it a medium-sized snake.

Diet- Data for rinkhals diet were as follows: One rinkhals specimen was observed feeding on an *Amietia fuscigula* while another was seen chasing a rodent (Jacobsen, 1989). Another one was observed feeding on a *Smaug giganteus* (Jacobsen et al., 1989). Parusnath (2012) recorded predation by a rinkhals on a neonatal sungazer lizard *Smaug giganteus* in the Welkom district of the Free State on 10 October 2012. Rose (1950) recorded 17 *Bufo angusticeps* from a specimen taken on the Cape Flats in the Western Cape. Pringle (1954) makes mention of a rinkhals caught under a haystack which disgorged 22 young mice.

In November 1991 during rainy weather, WRS observed a sub-adult feeding on a *Cordylus vittifer* in western Gauteng. Captive specimens held at Transvaal Snake Park readily accepted laboratory mice (WRS pers. obs.). Rodents and toads are mentioned by Branch (1998) as constituting their diet. A comparative study of diets between *Aspidelaps*, *Naja* and *Hemachatus* demonstrated that *Hemachatus* was the most specialised with 80% of their diet consisting of amphibians (Anura), although lizards and birds were recorded (Shine et al., 2007). Several specimens recorded by the authors have were also in the act of ingesting amphibians or disgorged an amphibian after capture.

Reproduction & fecundity- Historical data for rinkhals reproduction were as follows: A female rinkhals from Lothair gave birth to 63 young, the largest number of young known. 28 young were recorded by FitzSimons (1919) p. 184. In Port Elizabeth, rinkhals gave birth in the months of January, February and March. Haagner (1991) reported on a captive female which

originated from Olifantsfontein in Gauteng that gave birth to 21 stillborn and three live young on 27 December 1988. Mean length of the young was 211mm. A female killed near Bethlehem in the Free State contained 19 embryos in her left oviduct and 18 in the right (5th January 1950). One of the embryos was dicephalic (Haagner, 1994). FitzSimons (1962) stated the mean was between 20 and 30 while a specimen from Lothair gave birth to 63 young at the Durban Snake Park. Presumably, this is the same specimen reportedly exceeding 1.5 m in length (Broadley, 1990). This number is repeated by Branch who also states 20-30 live young are born in late summer (December-March) (Branch, 1998). Female *Hemachatus* produce a greater mean litter size than their close relatives *Aspidelaps* and *Naja*. The high fecundity in this species may be attributable to the stocky build of females and other species-specific selection pressures (Shine et al., 2007). The study by Shine et al. (2007) however did not distinguish if there was geographic variation in average adult size and fecundity.

Behaviour and activity-Historical data for rinkhals activity were as follows: Branch (1998) noted that rinkhals are nocturnal, but sometimes active on cold days. This is contrary to observations by the authors in this paper. Rinkhals on the Gauteng highveld appeared exclusively diurnal, and particularly active prior to summer afternoon thundershowers. Jacobsen (1989) stated that rinkhals appear to be mainly diurnal. Diel activity varies geographically and seasonally but is mainly diurnal in the Highveld grasslands (Alexander, 1996). *Hemachatus haemachatus* is reported to be more nocturnal in the miombo woodlands of eastern Zimbabwe (Broadley & Cock, 1975). Alexander et al. (1999) demonstrated that rinkhals have a wide thermal tolerance. This would explain the wide distribution and elevational range occupied by rinkhals.

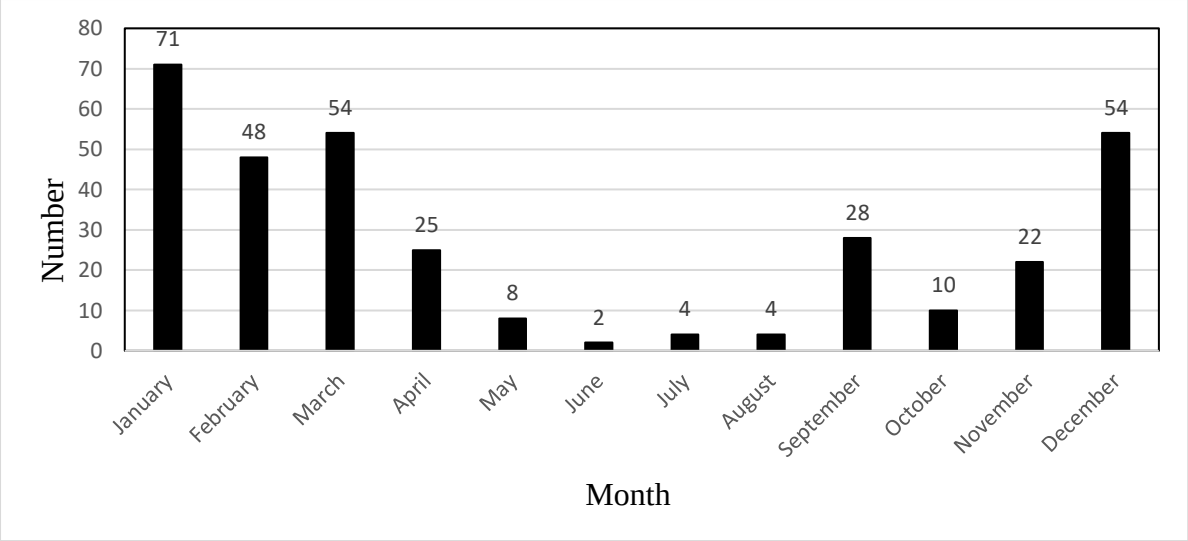

Figure 6.2: Seasonal activity from 330 records in the study area. High numbers corresponded strongly to the austral summer rainfall season.

Abundance- Historical data for rinkhals abundance were as follows: FitzSimons (1962) stated that the rinkhals was "very common in certain areas of its range, particularly the eastern Cape Province and the eastern Transvaal Highveld." Jacobsen (1989) highlights that although originally common in the highveld (citing Broadley, 1983), the species has declined in numbers due mainly to habitat destruction and road mortality. However, without prior population density estimates, this statement is difficult to quantify. In Jasobsen's study, 37.5% of specimens were collected dead on the road, indicating that road mortality may have a significant impact on this snake (Jacobsen, 1989). Surprisingly, despite its abundance in the Midrand-Kempton Park-Benoni region, relatively few specimens were observed as road-kill, despite regular commutes through the study area across all seasons (Figure 6.2).

Habitat-Historical data for rinkhals distribution were follows: The bioregions in which rinkhals are recorded are listed as Mesic Highveld Grassland, Sub-Escarpment Grassland, Dry Highveld Grassland, Central Bushveld, Sub-Escarpment Savanna, Albany Thicket,

Drakensberg Grassland, Southwest Fynbos and Eastern Fynbos-Renosterveld (Alexander, in Bates et al., 2014). These snakes also have a strong association with riparian environments such as wetlands, rivers, pans and the surrounds of dams (Figure 6.3; Broadley, 1990; Branch, 1988; Smith, 2011).

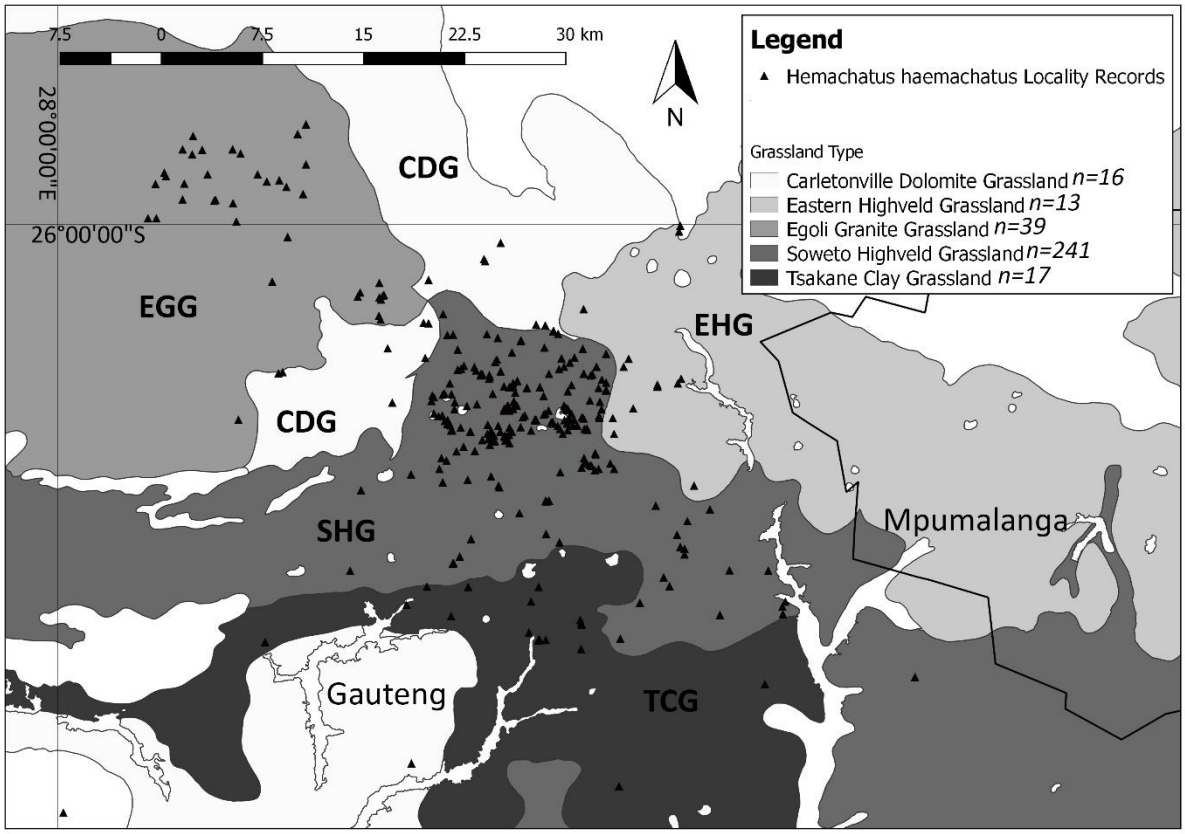

Figure 6.3. Vegetation overlay showing the five grassland types from where *Hemachatus haemachatus* was recorded.

6.6 DISCUSSION

From the above results, *Hemachatus haemachatus* is clearly surviving, and even thriving, within a peri-urban environment, where anthropogenic induced stresses are prevalent. Yet anecdotal observations from the Cape Town region in the Western Cape and the Inyanga region

in eastern Zimbabwe suggest that populations have declined dramatically and in eastern Zimbabwe may be locally extinct (Smith 2011; Broadley 2018).

Hemachatus haemachatus was officially unknown in Zimbabwe (then Rhodesia) until 1961. A forestry officer named Mr J. W. Barnes, who was based at Inyanga between 1911 and 1922, reported having seen around a dozen 'cobra' like snakes in the area, but identification remained unknown until 9 January 1961. During an expedition to Inyanga, D. Broadley examined three specimens collected by P. St J. Turnbull-Kemp, a senior warden based at the Inyanga National Park (Broadley, 1961; Broadley, 2018).

A museum expedition to search for the eastern Zimbabwean rinkhals was initiated on 16 November 2012 but failed to locate any further specimens. However, prevailing drought conditions may have thwarted efforts, although local people were shown photographs but did not recognize it. It is presumed to be extinct in the Troutbeck area and western areas of the Nyanga National Park (Broadley, 2013). The last museum specimen was reportedly collected in 1982 at the National Parks Trout Hatchery near Mare Dam by G. Putterill, and another specimen caught basking on the Bracken Hills Road 2km from Troutbeck in 1988 by Clive Meakin (Broadley, 2013). No further sight records or specimens are known from eastern Zimbabwe since these dates, making it over 30 years since the last one was observed. The eastern Zimbabwean specimens are also reported to be banded (i.e. Plate 11, Broadley & Cock, 1989).

Rinkhals in the Western Cape, in particular, within the Cape Town Metropolitan area, appear to be extirpated (Dorse et al., 2008). Historically, the species appeared to be abundant in the region, especially on the Cape Flats (Rose, 1950; Wingate, 1967). Visser (1979) recorded several specimens from the Kenilworth Race Course in the last ten years stating that "this locality is presumed to be the site of the only remaining population of this species on the Cape Peninsular." A study in the City of Cape Town metropolitan area by Smith (2011)

demonstrated that rinkhals are still present at certain sites, including Table Mountain National Park. Twenty four observations were made over a period of four months by the public, however, only four were conclusively confirmed. Further surveying is needed to infer population density and extent of occurrence within the City of Cape Town regions, as well as other parts of the Western Cape Province.

Rinkhals are medium-sized snakes with an average adult length ranging between 700 – 1300mm total length. Therefore, based on size, they are easily observed when detected. Reproductive fecundity is relatively high compared with other large elapid snakes (Shine et al., 2007), with average litter sizes of 20-30 young and a maximum of 63 being recorded. They are considered to be crepuscular or nocturnal in the Western and Eastern Cape as well as in Zimbabwe (Broadley & Cock, 1975; Branch, 1988), yet diurnal on the Highveld (Alexander, 1996). This is interesting as most of the Eastern and Western Cape populations are banded, a colour pattern trait generally found in nocturnal or crepuscular snakes, whereas the Highveld population is mostly uniform charcoal grey to black. KwaZulu-Natal snakes are also strongly banded, but relatively little published data exists as to their activity in KwaZulu-Natal. However, the Australian tiger snakes (*Notechis scutatus*) also show marked banding but are considered largely diurnal, preferring cool, moist areas (Wilson & Swan, 2003). *Notechis scutatus* shares several very similar lifestyle traits to *Hemachatus haemachatus* such as average adult size (800mm), fecundity (average 23 offspring) and diet (92% amphibians) (Shine, 1998). Rinkhals are catholic in their diet but show a strong preference to amphibians >80% (Shine et al., 2007).

Without detailed information on geographical variation in terms of lifestyle traits between populations, it is difficult to infer probable causes of decline in some populations. If Western Cape and eastern Zimbabwean populations are indeed nocturnal, could this be

contributing to low detection probability? Further research into activity patterns is required to answer this question.

The population of rinkhals is Gauteng is clearly thriving despite rapid urban development, particularly in the peri-urban-agricultural regions. A common attribute observed in these areas is the presence of wetlands, including man-made drainage ditches and storm-water funnels, as well as farm dams and ponds. These are all conducive to successful toad reproduction. The two most common toad species in the study area includes the guttural toad (*Sclerophrys gutturalis*) and the red toad (*Schismaderma carens*), and to a lesser extent, raucous toads (*Sclerophrys capensis*). In addition, the study area has historically included some of the largest giant bullfrog (*Pyxicephalus adspersus*) breeding aggregations in South Africa (WRS unpublished data). Several pans have been named after bullfrogs, including Bullfrog Pan in Benoni and Bullfrog Pan in Midrand. The extent of predation by *Hemachatus haemachatus* on *Pyxicephalus adspersus* is not known, but likely to be seasonally significant, as *Hemachatus haemachatus* is often found in close proximity to breeding sites. The above species of frogs are all seasonally explosive breeders with females producing very high numbers of eggs at the onset of summer rains. *Amietophrynus* spp. produce between 10 000 and 25 000 eggs; *Schimaderma carens* produce 20 000 eggs and *Pyxicephalus adspersus* produce up to 4 000 eggs (du Preez & Carruthers, 2009). The above species are diurnal and nocturnal. When WRS was based at Transvaal Snake Park in the mid-1990s, many problem rinkhals callouts coincided either just before, during or after afternoon thundershowers, a time when toad activity is heightened (WRS pers. obs.). There are increased numbers of various frog species in several urban areas of South Africa because of increased numbers of private swimming pools and irrigated residential gardens (Downs unpublished data). Furthermore, this has allowed some other avian species to exploit an urban environment (Singh and Downs, 2016).

Despite anthropogenic stresses placed on the environment in the study area, such as construction, agricultural tilting of land, heavy traffic volumes and general activity, *Hemachatus haemachatus* is relatively common, which goes against the trend of observations on snakes with similar lifestyle traits elsewhere (Todd et al., 2017). Rinkhals are also top contenders in human-wildlife conflict in the area. They are venomous and snake bites are potentially lethal to humans. They regularly bite dogs and can also squirt or spray their venom to a distance of 2 – 3 m. Many dogs and people have fallen victim to receiving venom in the eyes (various pers. comm.). Being predominantly diurnal in the study area, human-rinkhals encounters are common and therefore it stands to reason that many may be killed annually by property owners out of fear and ignorance. Yet, despite this, they are still common as indicated in this study.

Another factor which may be contributing to the success of rinkhals in suburban Gauteng is the selection of artificial refugia prolific in the area (WRS unpublished data), which provide suitable areas for thermal regulation and predator avoidance. These refugia include building materials such as bricks, tiles, wooden stack piles, holes in walls and under concrete foundations as well as corrugated iron sheets. Swimming pool pumps and French drains also provide suitable refugia. In terms of predators, a contributing factor towards population sustainability and possible growth in the area may be the lack of natural predators, such as mongoose or raptors which have largely been extirpated from the area.

Despite *Hemachatus haemachatus* being abundant in the study area, a range of future scenarios and/or environmental disturbances may lead to a population crash or even extirpation from the area. Urban ecology is a growing discipline and how anthropogenic influences affect biodiversity is critical in understanding the conservation needs of the organisms involved.

Even a relatively small decline in population abundance can result in large absolute losses of individuals and biomass which can disrupt ecosystem structure (Gaston & Fuller,

2007). In conservation strategies, common species usually receive much less attention than range-restricted threatened species. Recognition that common species are fundamental to the structure and integrity of ecosystems is as important as understanding the needs of more threatened species. The collation of historical records has shown that many common species have declined (IUCN www.redlist.org). A common example often given of a super-abundant species being driven to extinction over relatively short time frame is that of the passenger pigeon *Ectopistes migratorius*. Population numbers ran into the millions and some ornithologists have suggested that it may have been the most abundant bird on earth, but by the early 1900s it was extinct in the wild. Gaston and Fuller (2007) strongly recommend that more attention is given to common species that may in fact be declining yet receive little research. At particular risk are common species that are dependent on specialised widespread environmental conditions. Better monitoring programs are needed that can detect changes in the population trajectories of common species (Lindenmayer et al., 2011).

Understanding species traits and how they respond to threats may help prevent extinctions, especially for species of which we have very little data to identify declines. Snake species that feed primarily on vertebrates are more sensitive to human land-use. Research has found that increased extinction risk is greatly correlated with body size, habitat specialisation and trophic levels, but the threat decreases with larger range sizes and fecundity (Cardillo, et al., 2008; Böhm et al., 2016). Todd et al. (2017) used citizen science data to determine which traits were linked with sensitivity of snakes to anthropogenic land use. Those that occupy wetlands were demonstrated to be more sensitive to habitat disturbance. In this study there was no support for a link between reproductive mode and being venomous to snake declines (Todd et al. 2017).

In the case of rinkhals where over 80% of their diet includes amphibians, a dramatic decline in amphibian populations could have a detrimental impact on long-term population

viability. There is a notable correlation between amphibian declines and rinkhals declines in the Cape Peninsular and Cape Flats region. Rinkhals are generally not fast-moving snakes, therefore rodents and lizards are likely to be predated upon opportunistically, rather than intentionally. Their foraging mode is more conducive to hunting terrestrial amphibians such as toads (Bufonidae) and bullfrogs (*Pyxicephalus spp.*). This presents a very similar strategy as used by rhombic night adders *Causus rhombeatus*, which also feed primarily on toads and either actively forage for sheltering toads or will effectively chase and bite a moving toad (pers. obs.). Therefore, if the toad or frog population is depleted in a specific area, then rodents or lizards may not effectively support the rinkhals population largely because of the increased challenges in capturing such active prey items.

At least two toad species have declined dramatically in regions of the Cape Town area where rinkhals were formerly recorded and even abundant. *Sclerophrys pantherina* has declined on the Cape Peninsula and Cape Flats as a result of permanent habitat loss and fragmentation. *Vandijkophrynus angusticeps* has experienced greater than 50% reduction in abundance and in areas where they were formerly common such as Rondebosch Common (Rose, 1929), they have been extirpated (Minter et al., 2004).

Another factor which might be influencing population dynamics and detectability of rinkhals in some parts of their range is competition for resources and predation pressure from other species, including snakes. Intraspecific competition with the Cape cobra (*Naja nivea*) may explain why these rinkhals appear to be largely nocturnal in the Western and Eastern Cape, whereas in the highveld they are free from competition by other large, diurnally active elapids. This is further demonstrated in the Free State where *Hemachatus haemachatus* is mostly confined to the eastern Mesic Highveld Grassland Bioregion and *Naja nivea* to the western Dry Highveld Grassland Bioregion. However, the two species occur sympatrically around Klerksdorp and Potchefstroom in North West Province, as they do in the Western and Eastern

Cape. Snakes from North West Province are also diurnally active. Added to this, *Naja nivea* is known to prey on other snakes and rinkhals are likely to be preyed upon (Layloo et al., 2017). The same predation pressures might be playing out in eastern Zimbabwe where the range of rinkhals overlaps with that of the large cobra *Naja annulifera*, which is also well documented in preying on other snakes. Therefore, predator avoidance strategies may be driving *Hemachatus haemachatus* to becoming more nocturnal in these areas of overlap. However, *Naja annulifera* is equally nocturnal in the savanna biome, but may be more diurnal at higher and cooler elevations. This hypothesis will need to be tested further from across the mentioned species ranges, and also to determine if this varies seasonally.

Future research direction:

1. Genetic sequencing of rinkhals from throughout their distribution range is needed to understand genetic diversity between populations. Is the genetic structure significantly different between populations found in the Western Cape, Gauteng and eastern Zimbabwe?
2. Are there physical barriers preventing genetic dispersal between rinkhals populations and are these barriers created by urban-agricultural development or road networks?
3. Is there different diel activity between regional rinkhals populations, i.e. diurnal vs nocturnal and what are the drivers behind this? Is activity influenced by seasonal or regional climatic variables or caused by intraspecific competition by sympatric elapid snakes, such as the Cape cobra *Naja nivea*?
4. Is there regional variation in average rinkhals adult length? Do Highveld rinkhals grow larger than snakes from elsewhere?
5. Is there regional variation in fecundity between rinkhals populations?

6. Further dietary analyses, by possibly using DNA barcoding, in order to identify amphibian prey to species level, and correlate this to rinkhals population structure within rinkhals.
7. More detailed distribution sampling at a finer resolution is required to understand population dynamics of rinkhals. Ideally, several 'control' sites should be set up in partnership between problem snake catchers and conservation departments to monitor populations over time. However, logistical and financial constraints as well as competency in data capturing may thwart efforts in this regard. Also, considering that rinkhals are venomous snakes that could inflict a potentially fatal bite, many snake catchers might object to physical handling of the snake for data collection, such as making measurements or inserting PIT tags, even if using a tubing method of restraint.
8. A concerted effort should be made to log details on sex and size class on all snakes captured during problem callouts in order to infer more detailed population structure. Again, limitations as pointed out in point 7 may prevent robust data capture.

6.7 CONCLUSIONS

There is a strong, viable population of rinkhals in Gauteng Province despite anthropogenic transformation of the landscape. We predict that abundant prey in the form of amphibians, especially toads, favourable refugia and decreased predation pressures all contribute to the success of *Hemachatus haemachatus* in parts of Gauteng Province, despite associated risks of road mortality and human-wildlife conflict. Further sampling and surveys are required in regions where perceived declines are noted to determine if this is a result of lower detectability rates due to nocturnal or crepuscular activity. We predict that if this is the situation, nocturnal or crepuscular activity is influenced by resource partitioning between other large elapid snakes which occur sympatrically and which may even predate upon rinkhals. We suggest that

common species receive equal attention to that of rare or range-restricted species as published data shows that even common and widespread species experience dramatic population declines which can even lead to localised or complete extinction. We urge all problem snake catchers to keep accurate and detailed records of all snakes and have these submitted to suitable databases such as online virtual museums. Despite obvious limitations, these records may prove invaluable in the absence of long-term site monitoring in providing baseline data on population trends. A closer working relationship between conservation departments, problem snake removers and 'citizen science' contributions is encouraged.

6.8 ACKNOWLEDGEMENTS

The Gauteng Department of Agriculture and Rural Development (GDARD) is acknowledged for the necessary snake removal permits. We are grateful to the University of KwaZulu-Natal and the National Research Foundation (ZA) for funding CTD.

6.9 REFERENCES

Alexander, G. J. 1996. Thermal physiology of *Hemachatus haemachatus* and its implications to range limitation. Unpublished PhD Thesis, University of the Witwatersrand, Johannesburg, South Africa.

Alexander, G. J. & Marshall, C. L. 1998. Diel activity patterns in a captive colony of rinkhals, *Hemachatus haemachatus*. *African Journal of Herpetology* 47: 29-32.

Alexander, G. J & Brooks, R. 1999. Circannual rhythms of appetite and ecdysis in the elapid snake *Hemachatus haemachatus*, appear to be endogenous. *Copeia* 1999: 146-152.

Alexander, G. J., Mitchell, D. & Hanrahan, S. A. 1999. Wide thermal tolerance in the African elapid, *Hemachatus haemachatus*. *Journal of Herpetology* 33: 164-167.

Alexander, G. J., Hanrahan, S. A. & Mitchell, D. 2012. Assimilation efficiency and gut passage time in an African elapid snake, *Hemachatus haemachatus*. *African Journal of Herpetology* 61: 3-13.

Appelgryn, M. S. 1984. Johannesburg: origins and early management, 1886-1899. UNISA, Pretoria.

Bates, M. F. 1997. Herpetofauna of the nature reserves and national parks of the Free State province of South Africa. *African Journal of Herpetology* 46: 13-29.

Bates, M. F., Branch, W. R., Bauer, A. M., Burger, M., Marais, J., Alexander, G. J. & De Villiers, M. S. (eds) 2014. Atlas and Red List of the Reptiles of South Africa, Lesotho and Swaziland. *Suricata* 1. South African National Biodiversity Institute, Pretoria.

Böhm, M., Williams, R., Bramhall, H. R., McMillan, K. M., Davidson, A. D., Garcia, A., Bland, L. M., Bielby. J. & Collen, B. 2016. Correlates of extinction risk in squamate

reptiles: the relative importance of biology, geography, threat and range size. *Global Ecology & Biogeography* 25: 391-405.
Botts, E. A., Erasmus B. F. N. & Alexander, G. J. 2015. Observed range dynamics of South African amphibians under conditions of global change. *Austral Ecology* 40: 309-317.
Bourquin, O. 2004. Reptiles (Reptilia) in KwaZulu-Natal: I – diversity and distribution. *Durban Museum Novitates* 29: 57-103.
Boulenger, G. A. 1910. A revised list of the South African Reptiles and Batrachians, with synoptic tables, special reference to the specimens in the South African Museum and descriptions of new species. *Annals of the South African Museum* 5: 455-538.
Boycott, R. C. 1992. An annotated checklist of the amphibians and reptiles of Swaziland. Published by the Conservation Trust of Swaziland.
Branch, W. R. 1975. A bullfrogs meal. *African Wild Life* 29: 44.
Branch, W. R. & Braack, H. H. 1987 (1989). Reptiles and Amphibians of the Karoo National Park: A surprising diversity. *Proceedings of the 1987 HAA Stellenbosch Conference. J. Herp. Assoc. Afr.* 36: 26-33.
Branch, W. R. 1998. Field Guide to Snakes and other Reptiles of Southern Africa. Struik Publishers. 399pp.
Broadley, D. G. 1961. The mystery "dwarf cobra" of Inyanga identified at last. *Journal of the Herpetological Association of Rhodesia* 14: 3-4.
Broadley, D. G. 1983. FitzSimons' Snakes of Southern Africa. (Revised edition). Delta Books. 376pp.
Broadley, D. G. & Cock, E. V. 1989. Snakes of Zimbabwe. Bundu Series, Longman Zimbabwe. 152pp.
Broadley, D. G. 1990. FitzSimons' Snakes of southern Africa. Jonathan Ball and Ad. Donker Publishers, Parklands, South Africa.
Broadley, D. G. & Blaylock, R. 2013. The Snakes of Zimbabwe and Botswana. Edition Chimaira, Chimaira Buchhandelsgesellschaft mbH. 387pp.
Broadley, D. G. 2018. A Quest for African Herpetology. Edition Chimaira, Chimaira Buchhandelsgesellschaft mbH. 265pp.
Burger, M. 1993. The Herpetofauna of Anysberg Nature Reserve, Cape Province, South Africa. *Journal of the Herpetological Association of Africa* 42: 1-12.
Cardillo, M. Mace, G. M., Gittleman, J. L., Bielby. J. & Purvis, A. 2008. The predictability of extinction: biological and external correlates of decline in mammals. *Proceedings of the Royal Society, London*. Bulletin of Biological Sciences 275: 1441-1448.
Cott, H. B. 1935. The Zoological Society Expedition to the Zambesi, 1927: No 6: -On a collection of snakes from Portuguese East Africa. Proceedings of the Zoological Society, London (1934), pp. 963-975, 1 pl.
Dawson, P., Alexander, G. J. & Nichollis, S. 1991. The rinkhals (*Hemachatus haemachatus*), a southern African venomous snake – housing, husbandry and maintenance. *Animal Technology* 42: 71-76.
De Waal, S. W. P. 1978. The Squamata (Reptilia) of the Orange Free State, South Africa. *Memoirs of the National Museum, Bloemfontein* 11, pp. i-iii, 1-160.
FitzSimons, F. W. 1919. The Snakes of South Africa – Their venom and the treatment of snake bite. T. Maskew Miller, Cape Town.
FitzSimons, V. F. M. 1962. Snakes of Southern Africa. Purnell and Sons, Cape Town & Johannesburg.
Gaston, K. J. & Fuller, R. A. 2007. Commonness, population depletion and conservation biology. *Trends in Ecology and Evolution* 23: 14-19. Doi:10.1016/j.tree.2007.11.001
Gibbons. J. W. et al. 2000. The global decline of reptiles, déjà vu amphibians. *BioScience* 50: 653-666.

Haagner, G. V. 1991. *Hemachatus haemachatus* – Reproduction. Life History Notes. *Journal of the Herpetological Association of Africa* 39: 26.

Haagner, G. V. 1994. Life History Notes – *Hemachatus haemachatus* – Dicephalism. *African Herp News* 21: 22.

Jacobsen, N. H. G. 1989. A Herpetological Survey of the Transvaal. PhD Thesis, University of Natal, Pietermaritzburg.

Layloo, I., Smith, C. & Maritz, B. 2017. Diet and feeding in the Cape cobra, *Naja nivea*. *African Journal of Herpetology* 66: 147-153. https://doi.org/10.1080/21564574.2017.1388297

Lazenby, S. L. & Alexander, G. J. 1998. Do rinkhals (*Hemachatus haemachatus*) choose to defecate near water? *African Journal of Herpetology* 47: 25-28.

Liebenberg, A. G. 1998. Life History Notes: *Hemachatus haemachatus* Rinkhals – Arboreal Behaviour. *African Herp News* 27: 16-17.

Lindenmayer, D. B., Wood, J. T., McBurney, L., MacGregor, C., Youngentob, K. & Banks, S. C. 2011. How to make a common species rare: a case against conservation complacency. *Biological Conservation* 144: 1663-1672.

Masterson, G. P. R., Maritz, B., Mackay, D. & Alexander, G. J. 2009. The impacts of past cultivation on the reptiles in a South African grassland. *African Journal of Herpetology* 58: 71-84.

Minter, L. R., Burger, M., Harrison, J. A., Braack, H. H., Bishop, P. J. & Kloepfer, D. (eds) 2004. Atlas and Red Data Book of the Frogs of South Africa, Lesotho & Swaziland. SI/MAP Series #9. Smithsonian Institution, Washington, DC.

Moffat, R. 1990. Rinkhals and bokmakierie encounter. *Mirafra* 7: 49.

Mucina, L. & Rutherford, M. C. (eds) 2006. The Vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* 19. South African National Biodiversity Institute, Pretoria.

Parusnath, S. 2012. Natural History Notes: *Smaug giganteus* (A. Smith, 1844) Sungazer – Predation. *African Herp News* 58: 13-14.

Pringle, J. A. 1954. Common Snakes. Longmans, Green and Co.

Reading, C. J., Luiselli, L.M., Akani, G. C., Bonnet, X., Mari, G., Ballouard, J. M., Filippi, E., Naulleau, G., Pearson, D. & Rugiero, L. 2010. Are snake populations in widespread decline? *Biology Letters* 6: 777-780

Reed, D. H., O'Grady, J. J., Brook, B. W., Ballou, J. D. & Frankham, R. 2003. Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. *Biological Conservation* 113: 23-34.

Rose, W. 1950. The Reptiles and Amphibians of Southern Africa. Maskew Miller, Limited. Cape Town.

Rose, W. 1962. The Reptiles and Amphibians of Southern Africa. Maskew Miller, Revised Edition. 494pp.

Schmidt, W. R. 1999. Natural History Notes: *Hemachatus haemachatus* Rinkhals – Leucism. *African Herp News* 28: 38-39.

Shine, R., Branch, W. R., Webb, J. K., Harlow, P. S., Shine, T. & Keogh, J. S. 2007. Ecology of cobras from southern Africa. *Journal of Zoology* 272: 183-193.

Simelane, T. S. & Kerley, G. I. H. 1997. Recognition of reptiles by Xhosa and Zulu communities in South Africa, with notes on traditional beliefs and uses. *African Journal of Herpetology* 46: 49-53.

Smith, G. 2011. The status of the Rinkhals *Hemachatus haemachatus* in the City of Cape Town metropolitan area, Western Cape, South Africa. *African Herp News* 53: 13-16.

Singh, P. & Downs, C.T. Hadedas in the hood: Hadeda Ibis activity in suburban neighbourhoods of Pietermaritzburg, KwaZulu-Natal, South Africa. *Urban Ecosystems* 19: 1283–1293.

Todd, B. D., Nowakowski, A. J., Rose, J. P. & Price, S. J. 2017. Species traits explaining sensitivity of snakes to human land use estimated from citizen science data.

Vickery, H. 1989. An encounter with a rinkhals. *Mirafra* 6: 103.

Visser, J. 1979. New and reconfirmed records for the Cape Province with notes on some“rare” species (Sauria, Serpentes and Anura). *Journal of the Herpetological Association of Africa* 21: 40-48.

Welch, K. R. G. 1982. Herpetology of Africa. Robert E. Krieger Publishing Company, Malabar, Florida.

Wingate, L. 1967. Snakes Alive! Howard Timmins Cape Town.

CHAPTER 7

CONCLUSIONS

7.1 Overview

Globally anthropogenic effects on ecosystems and habitats and subsequent biodiversity loss is well documented across many taxa (Osborne et al., 1999; Craigie et al., 2010; WWF Living Planet Report, 2014). The causal factors leading to species declines is often multi-faceted and our understanding of the contributing factors leading to a species decline varies considerably between different taxonomic units (Gibbons et al., 2000; Reading et al., 2010). Traditionally, mammals and birds have received relatively greater attention compared with amphibians and reptiles. More recently, several well-studied declines affecting snakes have been documented in the literature showing their declines (Gibbons et al., 2000; Reading et al., 2010; Bates et al., 2014). Most studies emanate from North America and Europe, with a small percentage from Australia (Ujvari et al., 2016). Due to the absence of long-term site monitoring in Africa, the extent of snake population declines is mostly unknown and at best, speculative (Bates et al., 2014; Tolley et al., 2016).

My study aimed to provide baseline data on snakes from South Africa based on long-term field observation and accumulative data spanning a period of approximately 30 years, from 1988 – 2018. In my experience, I have documented declines in several geographical regions, including species-specific snakedeclines. Whilst the primary focus of this study was on snakes, these declines extend to other amphibian and reptile species, and brief reference is made to these in the specific site studies.

Firstly, I reviewed the published literature globally pertaining to snake conservation, population ecology and documented snake population declines and the contributing factors thereof (Chapter 1). The causes of decline are complex and often interlinked, having a

cascading effect. For example, a population of snakes isolated by roads and urban development will become genetically isolated, leading to weakened immunity and increased stresses, making them susceptible to disease and overloaded parasite burdens. Therefore, a population experiencing declines is affected by several interlinking causes. All contributing factors must be carefully analysed to initiate mitigation measures to prevent further decline (Chapter 1).

Secondly, I reviewed our current understanding of global snake diversity, conservation and systematics to quantify species diversity and conservation trends in extant snake species (Chapter 2). This highlighted that we are far from understanding true snake species diversity with numerous new species being described by science annually. Systematics and taxonomy, including phylogenetic relatedness, are all crucial aspects required to facilitate and implement effective conservation measures if we are to conserve world snake diversity (Chapter 2).

Thirdly, I presented snake data pertaining to road mortality based on a study undertaken along the R516 national road in Limpopo Province, South Africa (Chapter 3). Road mortality has been identified as a contributing factor of snake population declines in many regions of the globe (Andrews & Gibbons, 2005; Andrews et al.2008). The increasing network of roads and associated vehicular traffic is cause for concern, not only in protecting snakes, but other faunal species as well (Chapter 3).

I then examined data from personal archived records taken at two different, well-defined, field study sites – one site situated in a former grassland habitat in Gauteng Province, which is now completely transformed (Chapter 4), and a second site on the lower South Coast of KwaZulu-Natal Province (Chapter 5), which has experienced relatively lower rates of anthropogenic habitat transformation. Both sites have been randomly surveyed for a period spanning approximately 30 years and may represent two of the longest-running site specific herpetological surveys undertaken in southern Africa. The impact of anthropogenic habitat transformation through ecological succession and urban development on snake species

populations and diversity is discussed in detail. In the absence of consistent, methodologically robust surveys using trap arrays and mark-recapture studies, which are absent in South Africa, long-term field observation may be the only available option in identifying possible snake declines. This sentiment is echoed elsewhere across the globe where numerous seasoned herpetologists have indicated that snakes have declined in their respective field sites in recent decades. My data support this (Chapters 4 and 5).

I selected a common, widely distributed snake species, the rinkhals (*Hemachatus haemachatus*), as a species-specific candidate (Chapter 6). These elapid snakes appear to have experienced dramatic declines in some parts of their range, i.e. the Western Cape and eastern Zimbabwe, but which are still thriving within a peri-urban environment on the eastern highveld in Gauteng. Factors contributing to its success or decline are discussed (Chapter 6). This species can persist in Gauteng in suburban areas as it is an urban exploiter here.

In conclusion, our current lack of long-term monitoring is highlighted, as well as challenges and possible solutions and methods to gain better insight and understanding of snake population declines regionally and globally. The pros and cons of utilizing citizen science, virtual museums and social media data sets is discussed within the context of providing skewed data that may mask underlying population trends, providing a biased output which may in turn affect accurate conservation assessments. This thesis aims to be a qualitative study rather than a quantitative analysis. This thesis is the result of several decades of practical field observation. It highlights the value of anecdotal data capturing which may assist in analysing population trends over time and providing baseline data on which to build more robust models for conservation analysis. During approximately 30 years of work in herpetological research, conservation and invasive species management, the impact of anthropogenic habitat destruction and environmental degradation has been alarming, despite South Africa having some of the best environmental laws and implementation agencies. The need for urban

development, job creation and other socio-economic factors must be acknowledged in any conservation initiative, but it is critical that this be done in a sustainable and environmental manner. The results of countless global studies, many referenced in this thesis, is demonstrating unprecedented decline in invertebrates, fishes, amphibians, reptiles, birds and mammals. The contributing factors are glaringly obvious but quantifying and empirically showing and demonstrating these declines has its challenges. However, it is critical that we address and highlight these declines and initiate remedial measures before biodiversity is lost and we witness a catastrophic ecological collapse. This information must be communicated strategically to politicians and disseminated throughout places of learning. Public awareness and support are key to slowing down the unsustainable consumption of Earth's natural resources.

7.2 A cautionary note of data interpretation

How we use and interpret data are key elements in environmental conservation. Baseline data are used to inform conservation policy and contributes to the formation of the Red Lists under the auspice of the International Union for the Conservation of Nature (IUCN). Population trends may be misinterpreted by the method of data collection. In the last decade, the Internet and technical advancements in large online databases where the public can upload biological records have increased dramatically. For example, platforms such as iSpot (https://www.ispotnature.org/) and iNaturalist (https://www.inaturalist.org/) and regional online databases such as the Virtual Museum administered in South Africa by the Animal Demography Unit (http://vmus.adu.org.za/), have provided researchers with a wealth of data. These data can be used for mapping species distributions, but also for interpreting population dynamics. They must be interpreted with caution, as inflated contributions from the public

based on increased awareness, and therefore increased contributions), may mask actual population trends. I have attempted to demonstrate this in the infographics presented below.

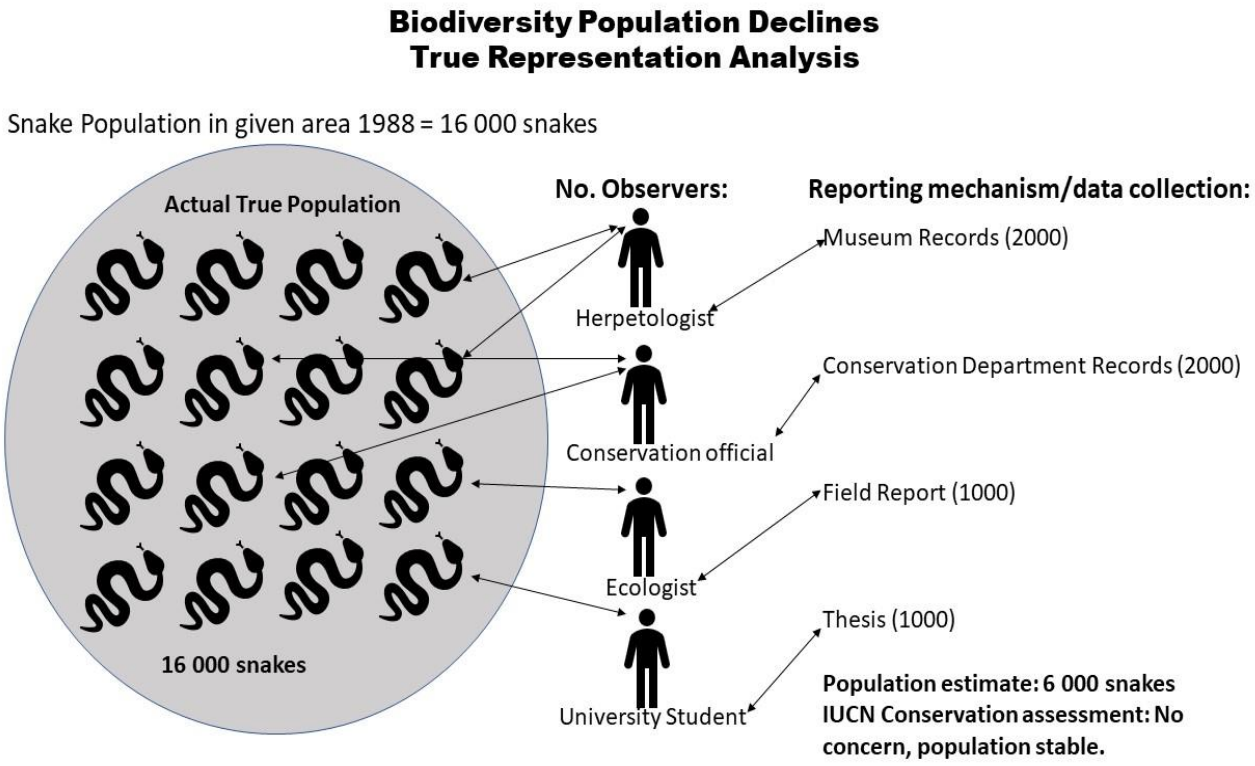

Figure 7.1. A hypothetical scenario on data collection based on limited number of observers contributing and collating data for conservation assessments.

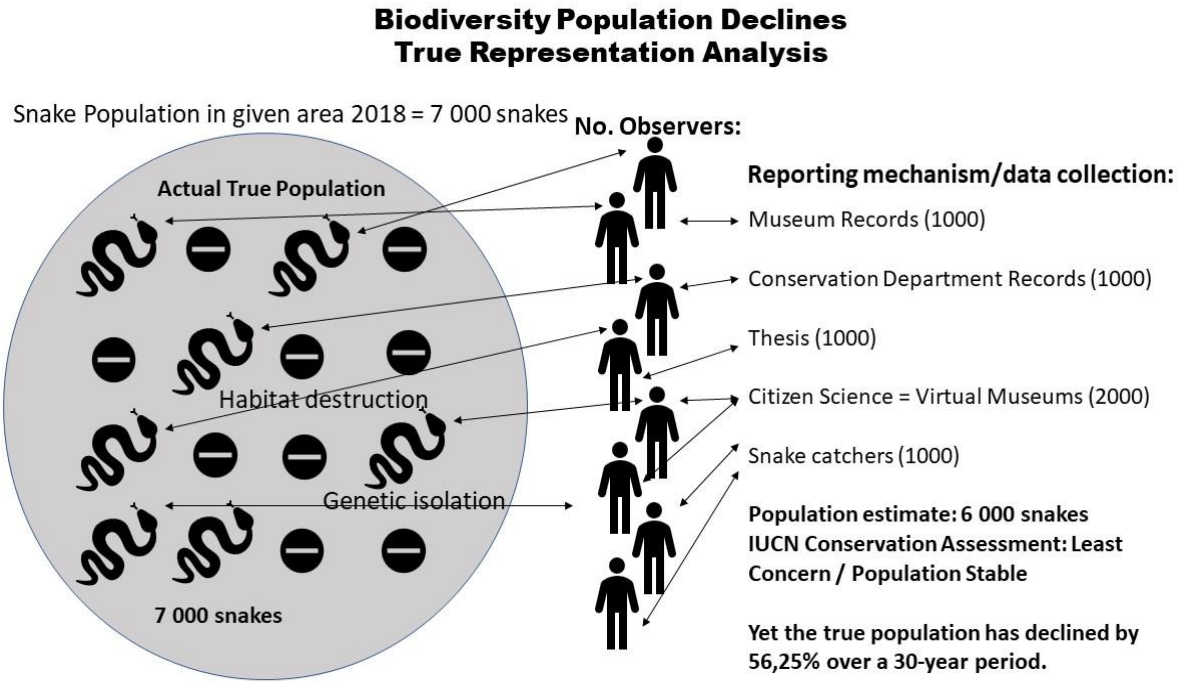

Figure 7.2. An incremental increase in number of observers results in the same number of contributed records, indicating that the population is stable, when in reality it has declined by almost 60%.

7.3 A proposal for future animal population studies and biodiversity monitoring

Data collection is widely acknowledged as being a critical component in conservation planning. However, logistical, practical and financial constraints are often barriers to long-term site monitoring. Monitoring programmes are more biased toward protected areas where scientists can gather data, but this may be limited to certain species such as rhinoceros (*Ceratotherium* spp.) or African elephant (*Loxodonta africana*) populations, or perhaps birds. Smaller invertebrates may go completely unnoticed and perhaps feature in a once off survey. In my own experience, time and financial constraints have greatly limited by field time, and therefore there is disparity in methods of data collection. Therefore, interpreting data analytically,

becomes challenging. As a final recommendation, the Department of Environmental Affairs, together with its biodiversity implanting agency, the South African National Biodiversity Institute (SANBI), should consider setting up several long-term site monitoring stations in all Biomes across South Africa. This should form part of a 100-year monitoring plan at the very least, and must incorporate all forms of biodiversity, including the smallest invertebrates to the largest mammals. Robust sampling and monitoring techniques can be developed based on best practice methods.

7.4 References

Andrews, K.M. & Gibbons, J.W. 2005. How do highways influence snake movement? Behavioural responses to roads and vehicles. *Copeia* 2005: 772-782.

Andrews, K.M. Gibbons, J.W. & Jochimsen, D.M. 2008. Ecological effects of roads on amphibians and reptiles: a literature review. *Herpetological Conservation* 3: 121-143.

Bates, M.F., Branch, W.R., Bauer, A.M., Burger, M., Marais, J., Alexander, G.J. & De Villiers, M.S. (eds). 2014. Atlas and red list of the reptiles of South Africa, Lesotho & Swaziland. *Suricata* 1. South African National Biodiversity Institute, Pretoria.

Craigie, I. D., Baillie, J. E. M., Carbone, C., Collen, B., & Hutton, J. M. 2010. Large mammals population declines in Africa's protected areas. *Biological Conservation* 143: 2221-2228.

Gibbons, J.W., Scott, D.E., Ryan, T.J., Buhlmann, T. D., Metts, B.S., Greene, J.L., Mills, T., Leiden, Y., Poppy, S. & C.T. Winne. The global decline in reptiles, Déjà Vu amphibians. *BioScience* 50 (8): 653-666.

Osborne, W. S., Hunter, D. A. & Hollis, G. L. 1999. Population declines and range contraction in Australian alpine frogs. In: Campbell, A. (ed) *Declines and disappearances in Australian Frogs*, pp.145-157. Environment Australia, Canberra, Australia.

Reading, C.J., Luiselli, L.M., Akani, G.C., Bonnet, X. Amori, G., Ballouard, J.M., Filippi, E., Naulleau, G., Pearson, D. & Rugiero, L. 2010. Are snake populations in widespread decline? *Biology Letters* 6: 777-780. doi:10.1098/rsbl.2010.0373

Tolley, K.A., Alexander, G.J., Branch, W.R., Bowles, P. & Maritz, B. 2016. Conservation status and threats for African reptiles. *Biological Conservation*. 204: 63-71. doi:10.1016/j.biocon.2016.04.006

WWF Living Planet Report 2014. https://www.worldwildlife.org/pages/living-planet-report-2014. Downloaded November 2018.