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Faculty of Tropical AgriSciences

Comparison of the herpetological diversity between different habitats and ecosystems in southern Namibia

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled “Comparison of the herpetological diversity between different habitats and ecosystems in southern Namibia” independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 14/05/20

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Germán Franco Polo

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Abstract

Increasing concern about the status and future of the world's biodiversity in the face of human-induced changes on land use and climate has focused attention on the need to mitigate the negative effects that these changes could have and protect nature. One of the elements to take into account in order to measure the biodiversity in an area is the distribution of the species that may be present in that area. Our knowledge about the distributions of a wide variety of organisms is improving constantly, in turn aiding us to take wise decisions in order to conserve and protect biodiversity. Nevertheless, not all groups have been studied with the same effort. Reptiles have been historically ignored in such issues, being one of the most punished groups by human indifference. This study focuses on comparing reptile diversity between habitats in two adjacent private areas, KumKum and Pelgrimrust, in southern Namibia, part of the arid Nama Karoo biome. To achieve our goals, a variety of sampling methods, both active and passive, were carried out in the different habitats of the study area in order to obtain an accurate depiction of the reptile community. In order to analyse the data obtained from the fieldwork, various parameters, estimators and diversity indices were calculated to provide the pertinent results using EstimateS and PAST software. During our fieldwork we were able to record 31 species distributed among the different habitats of our study area. Of the species recorded 15 were found only in one of the natural habitats (not considering Anthropic), being considered specialists, the rest of species were found in at least two habitats, being considered generalists. Most of these species lack an IUCN assessment. After calculating the diversity indices and effective numbers for the different habitats we observe that sandy plain habitat stands out, having twice the diversity as the rest of habitats. The results of the Jaccard index reflect higher similarity between sandy plain and rocky plain than between the other habitats.

Key words: Nama Karoo, Reptiles, Sandy Plain, Estimators, Sampling Methods

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All tables and figures shown in this MSc Thesis belong to the author of this study, except those in which a different authorship is explicitly indicated.

List of the abbreviations used in the thesis

IUCN……………………….	**International Union for Conservation of Nature**
GRA………………………..	**Global Reptile Assessment**
SABAP……………………..	**Southern African Bird Atlas Project**
TAP………………………...	**Tree Atlas Project**
SARCA……………………..	**Southern African Reptile Conservation Assessment**
EIS………………………….	**Environmental Information Service**
NSA………………………...	**Namibia Statistics Agency**
ACE…………………………	**Abundance-based Coverage Estimator**
DD…………………………..	**Data Deficient**
LC…………………………..	**Least Concern**
NT…………………………..	**Near Threatened**
VU…………………………..	**Vulnerable**
EN…………………………...	**Endangered**
CR…………………………..	**Critically Endangered**
EW………………………….	**Extinct in the Wild**
EX…………………………...	**Extinct**

1. Introduction and Literature Review

1.1. Introduction

Increasing concern about the status and future of the world's biodiversity in the face of human-induced changes on land use and climate has focused attention on the need to mitigate the negative effects that these changes could have and protect nature (Botkin et al. 2007). According to Magurran (2004), "biodiversity" could be defined as "the variety and abundance of species in a defined unit of study" and that can be divided into two components: species richness and evenness. "Species richness" is the number of species of a particular taxon that characterize a particular biological community, habitat, or region; this component is influenced by environmental factors such as topographic heterogeneity, annual mean temperature, and mean yearly precipitation (Engemann et al. 2015). "Evenness" is a measure of the homogeneity of abundances in a sample or a community in such a way that a community with the abundance of all the species equally distributed (the same number of individuals for all the species of the taxon considered) will be considered extremely even. In addition, we can distinguish three types of diversity. The species diversity (or richness) of a local community or habitat (α-diversity), the difference in diversity associated with different habitats or at spatial scale in the same habitat (β-diversity), and the total diversity of a region or other spatial unit (γ-diversity) (Colwell 2009).

One of the elements to take into account in order to measure the biodiversity in an area is the distribution of the species that may be present in that area. Our knowledge about the distributions of a wide variety of organisms is improving constantly, in turn aiding us to take wise decisions in order to conserve and protect biodiversity (Grenyer et al. 2006). Nevertheless, not all groups have been studied with the same effort. This represents an important gap in our understanding of the global structure of biodiversity and our ability to conserve nature (Roll et al. 2017). Reptiles have been historically ignored in such issues, being one of the most punished groups by human indifference. Carl Linneaus, "father of modern taxonomy", described reptiles and amphibians in his 1758 *Systema Naturae* as:

“These foul and loathsome animals are abhorrent because of their cold body, pale color, cartilaginous skeleton, filthy skin, fierce aspect, calculating eye, offensive voice, squalid habitation, and terrible venom; and so their Creator has not exerted his powers to make many of them.”

Thankfully, such opinions are disappearing as scientists reveal the significant roles that these animals play in subtropical and tropical arid areas, where hyper-arid environments cannot support large numbers of high-energy demanding mammals and consequent dependency on large amounts of water and nutrients (Herrmann & Branch 2013).

This study focuses on comparing reptile diversity between habitats in two adjacent private areas, KumKum and Pelgrimrust, in southern Namibia, part of the Nama Karoo biome, a vast, open and arid region dominated by low bush vegetation, punctuated by a rugged terrain (Dean & Milton 1999). The region's flora and fauna are highly adapted to its harsh climatic conditions, although this fauna is facing threats derived from some human activities like grazing, mining, agriculture and the introduction of exotic plants (Tolley et al. 2016). Studies focused on reptile monitoring in southern Namibia are scarce, mainly as a result of difficult access and lack of facilities for scientists in these areas, with much more abundant studies carried out in other areas of the country or on the other side of the Orange River, in South Africa (Herrmann & Branch 2013).

To achieve our goals, a variety of sampling methods, both active and passive, were carried out in the different habitats of KumKum and Pelgrimrust in order to obtain an accurate depiction of the reptile community in the area. Passive methods included the installation of pitfall traps and the use of coverboards. Active methods were mainly based on the realization of transects (visual transects, stoning transects and fiberscope transects) together with periods of free search. In order to analyse the data obtained from the fieldwork, various parameters, estimators and diversity indices were calculated to provide the pertinent results. The information obtained will be shared with the author of the last monitoring carried out in this area in 2018, Theart et al. (unpublished), in order to publish an update of the species present in southern Namibia. On the other hand, the precise locations of each individual found will be ceded to **Atlasing in Namibia** citizen science project (EIS Namibia 2020).

1.2. Literature Review

1.2.1. Conservation Status and Threats to Reptiles

Taking into account molecular phylogeny studies and fossil records, the appearance of reptiles on the planet is dated between 250 and 300 million years ago, during the Paleozoic Era, being protagonists of a long and complex evolutionary history (Reisz et al. 2011). Due to high rates of cladogenesis in the Triassic and Jurassic periods (Vidal & Hedges 2009) reptiles diversified into an extensive group of animals adapted to a wide variety of environments and habitats ranging from temperate to hot and moist to arid. Nowadays, reptiles are a fundamental part in natural systems, carrying out duties as predators, prey, seed dispersers and commensal species. One of the most important characteristics of these animals is the capacity to serve as bio-indicators for environmental health due to their specific requirements (Thompson et al. 2008); making them particularly vulnerable to anthropogenic environmental changes and threat processes (Anderson & Marcus 1992). This factor makes reptiles a group of conservation concern.

Of the 11,050 described species listed in The Reptile Database (Uetz et al. 2020), only 60 % (6,671 species, excluding DD category) have been assessed properly by the International Union for Conservation of Nature’s (IUCN 2020). Furthermore, there are 1,441 reptile species listed in the IUCN Red List within Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN) and Vulnerable (VU) categories, which is 13 % of the species listed in The Reptile Database. Nearly the same percentage (10 %, 1,159 reptile species) is listed as Data Deficient (DD), making obvious that there are still many gaps in our knowledge regarding to the real reptiles situation. Roll et al. (2017) estimated that about one in five lizard species is threatened with extinction. Overall, threat levels in reptiles are slightly lower than those observed in other taxa such as mammals, but higher than in birds (Böhm et al. 2013), being reptiles associated to freshwater habitats, as terrapins, some of the most threatened groups (Buhlmann et al. 2009).

The list of factors and threats that can lead to reptile populations decline is extensive, including habitat alteration/destruction, pollution, over-collection for illegal trade or bushmeat consumption, introduced species and climate change (Fa et al. 2006;

Todd et al. 2010; Stanton et al. 2015). Böhm et al. (2013) estimated that agriculture and biological resource use represent the most common threats to terrestrial reptiles (74 % and 64 % of threatened species affected, respectively). Urban development (34 %), natural system modification (use of fire, damming, etc., 25 %) and invasive or problematic native species (22 %) also play an important role in threat to terrestrial species. Biological resource is also the most significant threat to freshwater and marine reptiles (87 % of threatened species), most of this threat stems from targeted harvesting of species. Reptiles are particularly sensitive to habitat degradation due to their comparatively low dispersal ability, morphological specialization, relatively small home ranges and thermoregulatory constraints (Kearney et al. 2009). Climate change factor is especially harmful for taxa whose sex-determination is temperature-dependent (Janzen 1994); therefore, increasing global temperatures may lead to sex-ratio unbalance and detrimental impact on a wide variety of reptile populations.

Despite the threats reptiles are facing globally, the number of known species is still increasing due to the implementation of molecular techniques that allow us to distinguish between cryptic species, and the investigation of poorly accessible areas (Albert & Fernández 2009). In fact, some authors argue that reptiles will soon emerge as the richest class of terrestrial vertebrates at current levels of species description (Meiri & Chapple 2016).

Conservation priorities often focus on regions of high biodiversity value in order to effectively invest conservation funds (Brooks et al. 2006). This strategy results in the biggest “bang for buck” by protecting the greatest number of species (Murdoch et al. 2007). The problem is that the assessment of biodiversity value often relies on the distribution and richness of certain indicator taxa, predominantly on plants, mammals and birds; making reptile and amphibian’s protection dependent on the congruence of their distribution patterns with those of other taxa. In general terms, the global pattern of reptile species richness and hotspots is largely congruent with that of all other terrestrial vertebrates combined. However, some reptile groups do not fit this statement, is the case of lizards, whose richness in arid regions is higher than for the rest of tetrapods (Roll et al. 2017). So additional areas rich in reptiles or threatened reptiles may be overlooked if conservation priorities are set based only on distribution patterns of non-reptilian taxa (Böhm et al. 2013).

Roll et al. (2017) revealed new priority regions for reptiles that are not currently perceived as relevant for tetrapods biodiversity conservation, predominantly arid and semi-arid habitats, including parts of Africa, Asia, Australia and South America. This unique diversity pattern of reptiles has important implications due to the low conservation costs of these locations, so may be especially attractive for conservation. In addition to this "taxonomic discrimination", a certain biogeographical bias is also evident, being Africa the less studied continent regarding to reptile richness (Meiri 2016).

1.2.2. Situation of African Reptiles

Africa is a large continent whose land surface, at about 30.37 million km^2, and geographic position allows for considerable diversity habitats ranging from true desert to tropical rainforest. Despite its significance, its biodiversity remains poorly-known, particularly in comparison to temperate regions of the world (Deikumah et al. 2014). Africa is home to at least 20 % of the world´s reptile species (Uetz et al. 2020) and rising due to the relatively scarce survey coverage, being very important areas eastern Arc Mountains, Albertine Rift, Cameroon Highland and arid southern Africa (Böhm et al. 2013). When compared to other reptile faunas, Africa is obviously sparsely sampled and understudied. Fortunately, the initiative IUCN Global Reptile Assessment (GRA) has substantially increased the number of species assessed in last years. Despite this factor, more than 25 % of reptile species in mainland Africa still being non-assessed, and 14 % of the assessed ones are listed as Data Deficient (IUCN 2020).

Site accessibility is highly correlated with the number of specimens recorded in a given area, and most specimens are found in close proximity to roads, cities, and rivers (Reddy & Da 2003). Even in southern Africa, the best-sampled region, the estimated species richness is based on data from point locations near major roads and cities in South Africa, where there has been a greater sampling effort (Bates et al. 2014). This could lead to misdirected conservation efforts at country and local levels (Pimm et al. 2014), as the cells corresponding to these areas, being comparatively well sampled, could be incorrectly considered as high species richness, underestimating the richness of poorly sampled areas (Botts et al. 2011). Distribution maps provided by organizations such as IUCN have proven to be useful (Lewin et al. 2016), however, these distribution maps show the same knowledge gap inherent in the data collected over decades, and richness patterns will shift to well-known areas that are represented in the distribution data sources (Tolley et al. 2016). These unreliable patterns of species richness for African reptiles could be improved by corrective methods such as rarefaction or species distribution modelling (Engemann et al. 2015; Real et al. 2017).

Tolley et al. (2016) analyzed the threats reported in conservation assessments for Threatened African reptiles and designed a Threat Index based on socio-economic traits of African countries, revealing that over 70 % of threatened species are impacted by agriculture (mostly subsistence agriculture), 50 % by resource extraction (usually unregulated), and approximately 30 % by urbanization. These data are consistent with those previously mentioned with respect to the most prevalent threats to reptiles globally, with habitat transformation for agriculture being the most important factor (Böhm et al. 2013). There are some countries with a high Threat Index, which are in the same areas that show the most serious data deficiencies (e.g., Ethiopia, Liberia, Rwanda, Sierra Leone), due to this lack of information, is extremely difficult to determine the true impact of threats on these areas. Currently, six African countries are among the 10 fastest growing economies in the world (Rwanda, Ethiopia, Côte d'Ivoire, Ghana, Tanzania and Benin), as population growth rate is also increasing (African Development Bank 2020). The environmental impacts resulting from this growth will not be easy to regulate or control, given the lack of strict environmental regulations in many African countries. In addition, countries with relatively low Threat Index and relatively good biodiversity information are not exempt of severe impacts on some species (Tolley et al. 2016). One example is the extinction of *Tetradactylus eastwoodae* as consequence of habitat loss in South Africa (Bates et al. 2014). As highlighted by Meiri and Chapple (2016), Africa should be considered as a priority in terms of biological discovery to achieve a successful mapping and conservation of its biodiversity.

Lewin et al. (2016) assessed the richness patterns of reptiles in Africa, quantifying the overlap in species richness of reptiles (including amphisbaenians, crocodiles, lizards, snakes and turtles) with the other terrestrial vertebrate classes and investigated the environmental factors underlying these patterns. As in other continents, overall reptile richness is largely congruent with that of other vertebrates, but patterns of lizard richness emerge as different from the other reptile and vertebrate groups, showing hotspots in arid ecoregions such as the Namibian savanna woodlands and Nama Karoo, among others.

1.2.3. Reptile Research in Namibia

Namibia is a dry country on the southwestern coast of Africa, bordered on the north by Angola, on the northeast by Zambia, on the west by the Atlantic Ocean, on the east by Botswana, and on the south-east and south by South Africa. The population of Namibia is just over 2.5 million people in an area of 825,615 km^2 (NSA 2020), being the second lowest densely human populated country in the world after Mongolia (Worldometer 2020). The country is covered by biomes ranging from sub-humid woodlands in the northeast to true desert on the west coast with large arid and semi-arid climatic regions (Spear et al. 2018) with a high number of reptile species. Currently at least 276 reptile species in 27 families are known to occur in Namibia. Lizards are the most numerous group with 165 species in 9 families, followed by snakes with 86 species in 12 families. Turtles are represented by 16 species in 5 families and amphisbaenians by 8 species, crocodilians only by *Crocodylus niloticus* (Uetz et al. 2020).

In Namibia is possible to find the most important arid hotspot of African reptiles in terms of evolution, the Namib Desert, one of the oldest (at least 80 million years) and driest deserts in the world (Hartley et al. 2005). It extends along the length of the Namibian coastline, and into southern Angola. The Namib Desert and adjacent semi-arid ecoregions are characterized by significant reptile diversity, with a high percentage of endemism (Griffin 2003) and radiations of Gekkonidae, Lacertidae, Scincidae and Psammophiidae families (Bauer 1999; Herrmann & Branch 2013). Bauer (2003) reviewed some of the first herpetological observations recorded by Germans in southern African from 1646 to the beginning of the German colonial period in Deutsch Südwest Afrika (now Namibia) in the 1880s. From that period to the present day, most contributions occur in taxonomy, natural history, and systematics. In recent years taxonomic revisions and phylogeny studies have been included, being also common physiological and ecological studies targeting a few species (Herrmann & Branch 2013).

Due to the extremely low population density, large areas experience scarce environmental pressure through anthropogenic activities, even from agricultural practices such as cattle or sheep ranching. However, Namibian reptiles are not exempt from threats. The low number of wetlands in Namibia leads to remarkable human impact of these areas and the installation of structures related to providing water to humans and their livestock. Mining for minerals degrades the natural environment over extended areas and rangeland mismanagement in agricultural areas has led to bush encroachment with effects on the local herpetofauna (Herrmann & Branch 2013). In addition, as consequence of climate change, aridity and drought conditions are intensifying as temperatures rise and rainfall variability increases (Spear et al. 2018).

Most studies have been carried out in locations like Windhoek, Swakopmund, around Gobabeb Training and Research Center, located in Namib Desert, and Skeleton Coast National Park. This is due to the infrastructure that exists at institutions of higher education or the availability of facilities for researchers (Herrmann & Branch 2013). Large areas of Namibia, such as most of the southern, eastern and northern areas, have not received much herpetological attention. Inventory and monitoring are useful tools for assessing current levels and changes in biodiversity that could have consequences for scientific and management purposes in areas where comprehensive studies of reptile communities are lacking (Yoccoz et al. 2001). Therefore, the establishment of species lists and assessment of relative species abundances is a priority for many of these areas (Muller et al. 2017).

During the last few years, citizen science is taking on an important role in the development and advancement of scientific projects, especially those related to the distribution of species, since anyone can report their observations (Bonney et al. 2009). Under this premise appears the project **Atlasing in Namibia** which, based on previous projects such as the **Southern African Bird Atlas Project** (SABAP) and the **Tree Atlas Project** (TAP), aims to develop data sets collected through citizen participation on different taxonomic groups in order to learn more about the distribution of species in Namibia (EIS Namibia 2020). Data from live sightings, road kill, photographs, camera traps, telemetry and any other records can be provided to the database. Despite these measures to improve data on species distribution, certain areas remain deficient in terms of registration of individuals due to the low human population that could collaborate with projects of this type. An example of such areas is southern Namibia, which mostly belongs to Nama Karoo biome.

1.2.4. The Nama Karoo Biome

Nama Karoo is a semi-arid biome that occupies most of the interior of the western half of South Africa and extends into the southern interior of Namibia; its extensive surface is 248,248 km^2. The word *"Karoo"* comes from the Khoi-San word "*kuru"* which means dry. The Nama Karoo interfaces with the Succulent Karoo biome to the west, the Desert biome in the extreme northwest, the Savanna biome to the north and northeast, the Fynbos and Albany Thicket biomes in its southern and south-eastern extremities, and the Grassland biome infringing on its eastern border (Mucina et al. 2006). This biome has multiple problems derived from unpredictable severe droughts; many key economic activities are dependent on water availability (Orti & Negussie 2019). The dominant land use is the farming of small stock and game farming with indigenous antelope species (Hoffman et al. 1999). Little of the Nama Karoo has been transformed from natural vegetation to crops or other forms of land use that threaten natural diversity. Most land is privately owned and less than 1 % of Nama Karoo biome is statutorily conserved by national and provincial agencies (Cowling 1986); in consequence the conservation status of the biome and its fauna depends mainly on local authorities and private land-owners (Mucina et al. 2006).

Underlying the Nama Karoo is a 3000 m thick succession of sedimentary rocks including the Cape Supergroup (of marine origin), followed by Dwyka tillites (deposited during the Carboniferous), and other fossil-rich sediments of the Karoo Supergroup that appeared as consequence of the drifting away of southern Africa from the south pole. Igneous activity 180 million years ago contributed to death of the diverse therapsid fauna due to huge explosions of basaltic lava deposits and also caused intrusion of dolerite layers into Karoo sediments (Meadows & Watkeys 1999). This marked the start of the Gondwanaland break-up 155 million years ago, when faulting-initiated erosion processes began molding the present Karoo landscapes. The strata of the Nama Karoo gave rise to rocky and sandy plains, interrupted by outcrops of igneous origin rocky formations and flat-topped mesas. The soils derived from these sedimentary rocks and igneous intrusions of the Nama Karoo are weakly structured.

One of the two dominant and shallow soil forms in the Nama Karoo is called Glenrosa, has a low erodibility on plains and gentle slopes, which increases with verticality of slopes of hills and mountains. The other dominant form in Nama Karoo is called Mispah, often found in association with Glenrosa, its erodibility is low. The deeper Hutton form soils are mainly derived from dolerite and granite and have a very low erodibility. In contrast, Sterkspruit and Swartland soil forms are highly erodible on sloping areas (Mucina et al. 2006).

Pollen grains from sediments suggests that around 70 million years ago (Cretaceous-Tertiary boundary) the climate was warmer and wetter than today, with dry forest containing probable ancestors of Fynbos that included Proteaceae-, Thymelaeaceae- and Ericaceae-like species in the understory (Scholtz 1985). Pollen suggests that Asteraceae-based shurbland flora that dominates the region today might have developed afterwards on the subcontinent during the early Cenozoic Era (Zavada & De Villiers 2000). This change to a biome that approach the modern Nama Karoo was consequence of a global cooling that resulted in the disappearance of the subtropical woodland vegetation that existed in the ancient Nama Karoo (De Wit & Bamford 1993). During the more recent Quaternary period (last 1.8 million years) there were fluctuations of the climate in the region. Pollen and sedimentary evidence suggests that during the Holocene (last 10,000 years) moisture fluctuations lead to shifts between grass and shrubs vegetation as consequence of sensitivity to changes in precipitation quantity or seasonality (Meadows & Watkeys 1999).

Nowadays, Nama Karoo temperature extremes range from -5 ºC in winter to more than 43 ºC in summer, and the mean annual precipitation (MAP) ranges from 70 mm in southern Namibia to 500 mm in some parts of the Eastern Cape, in South Africa (Mucina et al. 2006), although during the last few years, MAP in southern Namibia has been around 40 mm as consequence of severe droughts (World Weather Online 2020). This biome is classified, together with Succulent Karoo, as part of a large, climatologically and floristically heterogeneous Floristic Region called the Karoo-Namib Region (White 1983). In turn Nama Karoo biome can be subdivided into three bioregions called Bushmanland, Lower Karoo and Upper Karoo attending on the mean annual temperature and rainfall (Mucina et al. 2006).

Flora of Nama Karoo biome is not particularly rich (Cowling et al. 1998), small drainage lines support more plant species than surrounding plains (Milton 1990) and the biome does not contain any centre of endemism (Van Wyk & Smith 2001). This might be indicative of the youthfulness of Nama Karoo biome, where Asteraceae, Fabaceae and Poaceae are dominant flora families, including also elements of Fynbos and Succulent Karoo biomes like Aizoaceae, Crassulaceae and Euphorbiaceae species whose diversity and cover decreases to the north and east, as the contribution of grasses increases (Hilton-Taylor 1987). Despite relatively low floristic richness, the Nama-Karoo vegetation has a high diversity of plant life forms that include ephemerals, annuals, geophytes, C3 and C4 grasses, succulents, chamaephytes and trees. This is probably a consequence of the unstable nature of the region retarding to climatic conditions, which gives no advantages to any particular life form (Cowling et al. 1994). Given the unpredictability and aridity of the Nama Karoo region, vagile herbivores such as springbok (*Antidorcas marsupialis*), nomadic granivorous birds as lark-like bunting (*Emberiza impetuani*) and invertebrates with variable dormancy cued by rain are favored (Dean 2000; Mucina et al. 2006). These animals are considered "boom-bust" species that are able to respond quickly to nutritious post-drought regrowth, flowering and seeding, but when forage quality falls, they rapidly move to other areas or die (Skinner et al. 1986). Adaptations of plants for zoochory and defense against herbivores are uncommon in the Nama Karoo, except along rivers and near watering points where herbivores stay longer, exerting a great pressure on plants (Milton 1991).

Sadly, although the Nama Karoo is mostly intact, heavy grazing by livestock has left certain parts of the biome seriously degraded (Milton & Dean 2010). Vegetation recovery following drought can be delayed due to increased stocking rates that in turn exacerbate the effects of subsequent drought periods. Under conditions of overgrazing many indigenous shrubs may proliferate, while several grasses and other palatable species may be lost (Mucina et al. 2006), contributing to the gradual increase of land degradation in the Nama Karoo (Walker et al. 2018). In addition to pastoralism, the introduction of alien plant species, anthropogenic climate change, agricultural expansion, mining activities, the collection of rare succulents and reptiles for illegal trade, as well as the construction and failure of dams also threaten the Nama Karoo's biodiversity (Lloyd 1999; Rutherford et al. 1999; Mucina et al. 2006; Milton & Dean 2010).

Most of the reptile studies carried out in Nama Karoo has been conducted in the South African part of the biome (Conradie et al. 2016; Turner & De Villiers 2017). The most notable publication covering the herpetofauna of Nama Karoo biome is the **Atlas and Red List of the reptiles of South Africa, Lesotho and Swaziland**, developed by Bates et al. (2014), which is a result of the Southern African Reptile Conservation Assessment (SARCA) project. This project was carried out from 2005 to 2009 and had the aim of providing detailed distribution maps and information on systematics and phylogeny, ecology, threats and possible need of conservation measures for more than 420 taxa (species and subspecies) from South Africa, Lesotho and Swaziland. In addition, the Atlas published by SARCA project included a Red List with conservation assessments (global or regional, depending on the information available for each species) of all the described reptile taxa in these countries using IUCN criteria (De Villiers et al. 2010). Despite such important publication, the Namibian part of Nama Karoo is still neglected in terms of herpetological studies.

Studies focusing on reptile habitat preference and species richness of different habitats in arid environments are usually conducted on a large scale and based on environmental gradients (Brito et al. 2008; Carranza et al. 2018). Studies at a smaller scale are usually based on sites where habitats are highly heterogeneous with each other, sites that are quite far from the relative homogeneity that characterizes arid and semi-arid environments (Kurniati 2005). The present study aimed to evaluate the diversity of reptiles in KumKum and Pelgrimrust areas, located in the Karas region of southern Namibia, which belongs to the Nama Karoo biome. It was also intended to check whether this diversity changes depending on the natural habitat we consider within these areas. Diverse sampling techniques were used in order to avoid underestimating of species diversity and richness (Hutchens & DePerno 2009). Previous studies related to reptile diversity were carried out in this area by Theart et al. (unpublished), who stated that KumKum and Pelgrimrust are areas of high diversity and low abundance of individuals; being able to find 31 reptile species.

2. Aims of the Thesis

The present study aimed to evaluate the diversity of reptiles in KumKum and Pelgrimrust areas, located in the Karas region of southern Namibia, which belongs to the Nama Karoo biome. It was also intended to check whether there are differences in reptile biodiversity between the different habitats in the study area and, if so, which one of the habitats is the most diverse. To achieve this goal, a survey was carried out in the area using various methods, both passive and active, thus obtaining an updated inventory of the species present in the study area.

The IUCN Red List categories of the species present in the area were also checked on the basis of the evaluations carried out by the SARCA project and by IUCN itself.

3. Materials and methods

3.1. Study Area

Our study was carried out in two adjacent privately owned protected areas called KumKum (187 km^2) and Pelgrimrust (105 km^2) located in southern Namibia (Figure 1), in the Karas Region, limiting with South Africa, bordering the Orange River and belonging to the Nama Karoo biome. These areas have been secured with the vision of restoring and ecologically conserving this semi-desert mountain territory in the Nama Karoo biome.

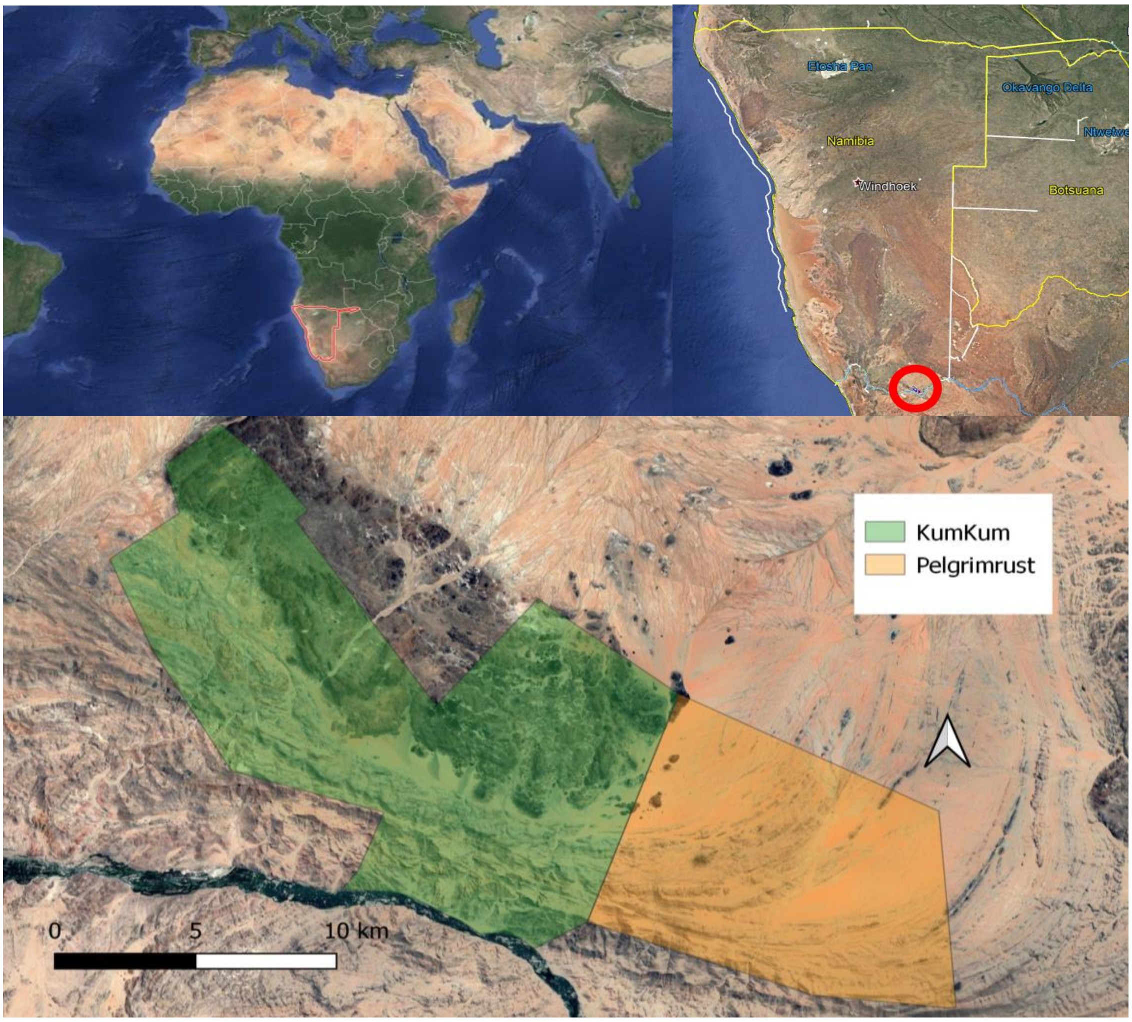

Figure 1. Location of the study area. Top left: location of Namibia in the African continent. Top right: location of the study area in Namibia. Bottom: study area.

Few years ago game hunting was the main activity on KumKum and Pelgrimrust areas, for this reason is common to find there small herds of ungulates like springbok (*Antidorcas marsupialis)*, common eland (*Taurotragus oryx)*, gemsbok (*Oryx gazelle*), kudu (*Tragelaphus strepsiceros*) and Hartmann´s mountain zebra (*Equus zebra hartmannae*).

The unique and heterogeneous topography of the area creates a mosaic of different habitat types, including vast sandy plains of compacted sand with sparse vegetation dominated by shrubs and dwarf shrubs, with annual and perennial grasses and herbs. Prominent lower shrubs include *Phaeoptilum spinosum*, *Boscia foetida* and *Cadaba aphylla*, while the dominant grasses include *Schmidtia kalahariensis*, *Stipagrostis ciliate*, *S. obtusa* and *S. uniplumis* (Koekemoer et al. 2014). Open shrublands on rocky plains, with little stones as main substrate, dominated by *Euphorbia gregaria* are also common. Basalt hills and low mountains with quarts outcrops and widely scattered low trees such as *Aloe dichotoma* and *Acacia mellifera*, whose branches usually carry the weight of huge communal nests of sociable weaver (*Philetairus socius*), trace the route of numerous dry riverbeds of loosely compacted sand that follow the topography of the land. These mountains are inhabited by groups of klipspringer (*Oreotragus oreotragus*) and rock hyrax (*Procavia capensis*), who remain vigilant due to the presence in the area of the leopard (*Panthera pardus*) as the main predator. Some species of small carnivores inhabits KumKum and Pelgrimrust, including black-backed jackal (*Canis mesomelas*), bat-eared fox (*Otocyon megalotis*), honey badger (*Mellivora capensis*), caracal (*Caracal caracal*), wildcat (*Felis silvestris*), aardwolf (*Proteles cristata*) and Cape grey mongoose (*Herpestes pulverulentus*), among others (Andrés-Criado & Neštický unpublished).

These four habitats are considered the natural habitats of the study area: (1) sandy plain, (2) rocky plain, (3) mountain and (4) riverbed (Figure 2). As mentioned in the previous paragraph, the main difference between them is the dominant substrate, vegetation composition and slope. We could consider a fifth habitat made up of the set of human constructions located in KumKum and Pelgrimrust, but obviously the character of this Anthropic habitat is different from that of the natural ones.

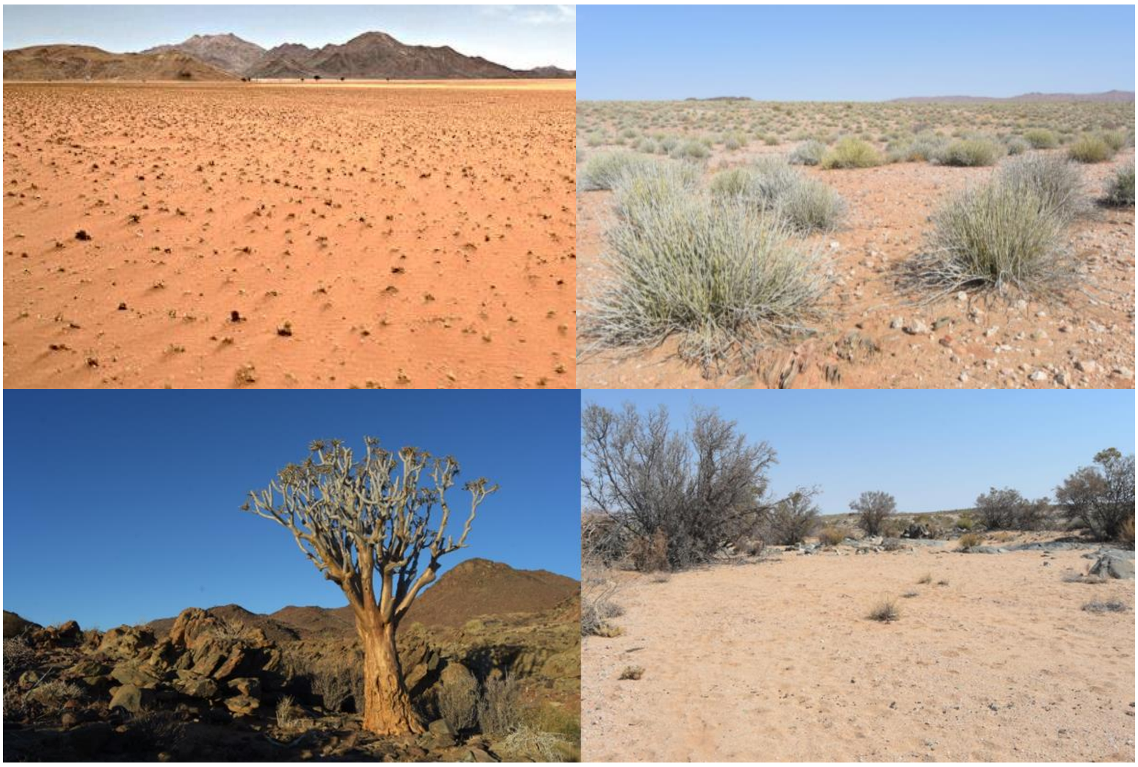

Figure 2. Natural habitats of the study area. Top left: sandy plain. Top right: rocky plain. Bottom left: mountain. Bottom right: riverbed.

Rainfall is limited in the region and water bodies are scarce, with some artificial watering holes scattered through-out the area. Due to the persistence of droughts during the 20th century, the Department of Agriculture of South Africa established plantations of drought-resistant alien species for forage of livestock. Unfortunately, this led to accidental invasions of some species of the genus *Prosopis*. The impact of invading alien trees on vegetation cover is likely to be significant in naturally treeless ecosystems such as the Nama Karoo (Rundel et al. 2014). *Prosopis* has serious negative environmental impacts, like the displacement of indigenous forage species, reducing rangeland grazing capacity (Roberts 2006). These invasive species are present in both of our study areas, but are more common in Pelgrimrust due to the presence of a herd of feral horses that feed on the *Prosopis* and spread the seeds.

3.2. Methods

3.2.1. Fieldwork Methods

Reptiles are among the most difficult groups to assess in field biodiversity studies due to the small size of some species and their secretive nature, being fossorial and cryptic species the most challenging to record (Gibbons 1988). On the other hand, environmental variables such as temperature, humidity, wind and season can influence the activity and detectability of many species (Williams & Berkson 2004; Vitt & Caldwell 2014). These adversities require the development and implementation of sampling plans combining direct (or active) and indirect (or passive) techniques that take advantage of individual activity patterns and preferences of each species to facilitate catches and analyses (Grant et al. 1992). Single trapping technique could not record all possible species in a particular area (Ali et al. 2018).

Passive capture methods are designed to retain the animals that enter the trap by themselves, accumulating captures that are then checked by the researcher, whose intervention is limited to the choice of sites, the installation of the traps and the verification of the captures. Passive traps are the most effective ways to sample rare or secretive reptile species in a highly standardized manner. A huge variety of passive traps have been developed for almost any habitat or situation; however, most of these traps are based on drift fences (Dodd 2010).

Drift fences are vertical barriers that intercept the intended trajectory of animals moving from one location to another. The fence typically guides animals toward a pitfall trap; these traps consist of some type of container that is sunk into the ground, with the rim level with the surface. Animals that fall into pitfalls are unable to climb out, becoming trapped. The use of this kind of trap with herpetofauna was firstly described by Gibbons and Bennett (1974); and Gibbons and Semlitsch (1981). The number of animals captured is a function of three major factors: (1) the density of animals within the area sampled, (2) the activity levels of those animals, and (3) the probability that an individual encountering a trap will be captured and not be able to escape (Dodd 2010). Pitfall traps can result in injury to captured individuals either due to physical stress, such as overheating, desiccation, drowning, or to predation (Gibbons & Semlitsch 1981).

The evolution of the drift-fence technique in herpetology has resulted in the use of a variety of construction materials for the fence. No single construction material or trap type is universally “the best” because of several factors whose importance will vary depending upon the particular project. As part of our research, three drift fences were settled on sandy soils in transition areas between habitats in KumKum area. Each drift fence was 20 m long and was made of fencing cloth, 3 sticks of 1 m, 8 sticks of 40 cm and galvanized wire to ensure the structure. Each drift fence were settled above 4 pitfall traps, in our case, plastic containers with a height of 21 cm and 6,6 m of separation between containers. Plastic containers are easily available and for field use, plastic is also lighter, less fragile and cheaper to replace than other materials (Brown & Matthews 2016). Part of the fencing cloth (10 cm) was burrowed in the sand, making the animals continue the way and no trespassing the fence from below, with 30 cm height over the sand. At both ends of the drift fence there is an arrow-shape structure with 80 cm length each side to facilitate the capture of the animals (Figure 3).

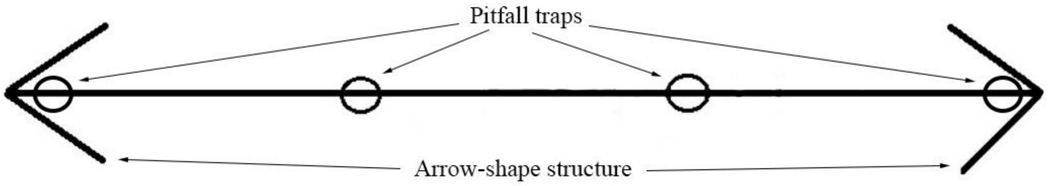

Figure 3. Schema of the aerial view of the drift fences and pitfall traps used during the field work. Note the arrow-shape structures at both ends of the drift fence.

This type of trap had a wet element inside (sponge) to avoid the dehydration of the captured individuals. In addition, it had a flat stone to avoid the suffocation because of the sun during the permanence inside the trap and to provide the animals of a hiding place (Figure 4). Passive traps restrain captured animals, so frequent monitoring of traps is necessary to avoid mortality or injuries of captured individuals. In our case the traps were checked twice a day, after the sunrise and before the sunset, each capture has to be written, with the details of which bucket and trap was the one occupied by the captured reptile. Other than checking traps daily, we made no attempt to prevent predation (e.g., by mongooses) on trap occupants. Some predation may have occurred, although we did not see obvious signs (e.g., tracks) of predator visitation.

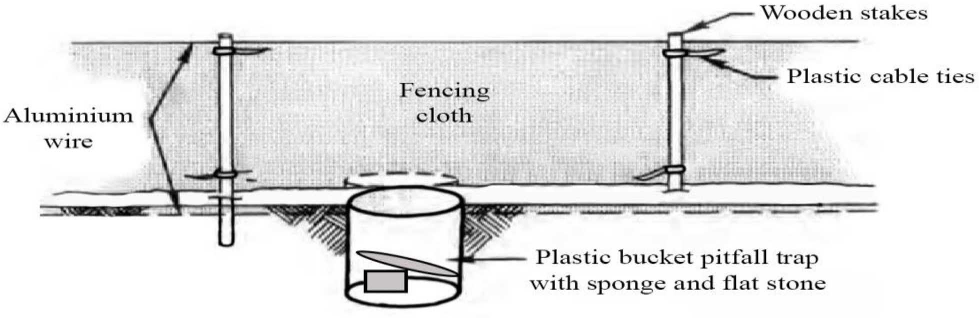

Figure 4. Detailed schema of a drift fence with pitfall traps. Note the presence of stone and sponge inside the buckets to prevent suffocation of the trapped animals. Figure modified from Gibbons and Semlitsch (1981).

Unlike passive traps such as pitfalls, some traps do not actually restrain or capture animals, but instead concentrate free-ranging animals to facilitate their capture by the researcher. One example is coverboard trapping, sections of cover material (usually wood or metal) which are placed on the ground in habitats preferred by target species by a researcher. Such traps generally operate on the principle of creating optimal microhabitats for the target species, attracting animals that can then be collected when the researcher lifts the coverboard (Dodd 2010). Two large coverboards (150 x 90 cm) and two small coverboards (90 x 80 cm) were settled surrounding each drift fence (Figure 5). So a total number of twelve wooden coverboards were checked daily. Advantages of the coverboard technique, relative to other surveying techniques, include its easy implementation (materials costs are low and little site preparation is needed) and low maintenance (Grant et al. 1992), furthermore coverboard trapping method poses a lower injury risk for the animals than other methods (Gibbons & Semlitsch 1981).

Figure 5. One of the drift fence and pitfall traps used during this study. Note the placement of the coverboards around the drift fence.

Active methods are sampling methods that involve a search effort by the researcher. These methods are theoretically much more effective for finding larger or highly mobile species due to their ability to escape from pitfall and other passive traps (Greenberg et al. 1994). In our case, transects were used as the main active method. Transects consist of defining a straight and delimited linear space, which is traversed by the observer at a constant speed, collecting data on the species observed during the walk. Three types of transects were implemented: (1) visual transects, the observer simply walks around and notes down the species and individuals sighted, (2) stoning transects, the observer lifted rocks and logs during the transect in search of individuals that might be hidden under such objects, and (3) fiberscope transects, the observer recorded burrows and voids during the transect using a fiberscope in search of individuals that might be hidden in such places. This type of transects were carried out mainly during the morning to detect diurnal species and at sunset and first hours of night, when vespertine and nocturnal species start their activity. Transects were complemented with free search periods of variable duration with the aim of completing the inventory of species in the area by registering specific species whose detection depends on their intensive search in favourable habitats according to their requirements. The spatial location of specimens and transects was georeferenced using the app Geo Tracker, using the WGS84 coordinate system, and downloaded into a database with an interface for a Geographical Information System (GIS). The different species found were identified using field guides (Marais 2004; Alexander & Marais 2007) and the support of iNaturalist community.

3.2.2. Data Analysis Methods

Rank-abundance bars were displayed in order to visualize the species and families abundance distribution for each habitat and for the general protected area. Species (or families) are plotted in sequence from most to least abundant along the X-axis. One advantage of a rank plotting is that contrasting patterns of species richness and evenness are clearly displayed (Smith & Wilson 1996).

Sample-based rarefaction curves have been used to illustrate the rates at which new species are added to the inventory, providing important clues about the species richness and species abundance distribution. These curves plot the cumulative number of species recorded as a function of sampling effort (Colwell & Coddington 1994). The order in which samples or individuals are included in a species accumulation curve influences its shape, for example, an especially speciose sample will have a much greater influence on the shape of the curve if it is encountered earlier rather than later in the sequence (Magurran 2004). This effect can be avoided randomizing the procedure in such a way that samples are randomly added to the species accumulation curve. The procedure is repeated, in our case, 100 times. It is important to note that a community generally consists of a large number of species with relatively low abundances. When sampling is done and each individual is recognized taxonomically, some rare species in the community may not be represented in the sample because the sampling effort invested is often insufficient to record all species. The result is that the diversity observed in the sample is often less than the diversity that would be expected to be found in the community (Moreno et al. 2011). To overcome this problem, non-parametric estimators have been generated to estimate the total diversity of the community. These estimators are a very useful tool to know if a second study is required in an area, even when an asymptote is obtained in the sample-based rarefaction curve, non-parametric estimators can tell us whether is necessary to increase the sampling intensity or whether is possible to reduce it in order to save costs.

Sample-based rarefaction curves and estimates of the total species richness of each habitat (α-diversity) and the protected area (γ-diversity) were obtained using EstimateS Software Version 9.1.0. Two estimators were used. Chao1 estimator is based on abundance; this means that the estimator requires data about the number of individuals belonging to a certain class (species) in a sample (Magurran 2004). In our case, a sample is a list of reptile species in a specific habitat during a specific sampling event. There are many species that are only represented by few individuals in a sample (rare species), compared to common species, which may be represented by numerous individuals. Chao1 estimator requires knowing which species are represented by a single individual in the sample (singletons), and which species are represented by exactly two individuals (doubletons):

$$S_{Chao1} = S_{obs} + \frac{F_1^2}{2F_2}$$

S_{Chao1} is the number of classes (in this case, number of species) that we want to know, S_{obs} is the number of species observed in a sample, F_1 is the number of singletons and F_2 is the number of doubletons.

The estimate of species richness produced by Chao1 is a function of the ratio of singletons and doubletons and will exceed observed species richness by ever greater margins as the relative frequency of singletons increases. No further increase in the estimate is achieved once every species is represented by at least two individuals and at this point the inventory can be considered complete (Coddington et al. 1996).

The abundance-based coverage estimator (ACE) recognizes that species that are abundant are likely to be included in any sample and thus contain very little information about the overall size of the assemblage (Chao et al. 2000), so this estimator only consider species with between one and ten individuals. The estimate is completed by adding on the number of abundant species, those represented by >10 individuals (Magurran 2004):

$$S_{ACE} = S_{abund} + \frac{S_{rare}}{C_{ACE}} + \frac{F_1}{C_{ACE}} \gamma_{ACE}^2$$

S_{ACE} is the number of classes (in this case, number of species) that we want to know, S_{abund} is the number of abundant species (>10 individuals), S_{rare} is the number of rare species (≤ 10 individuals), N_{rare} is the total number of individuals in rare species, F_i is the number of species with i individuals (F_1 is the number of singletons), $C_{ACE} = 1 - F_1/N_{rare}$ and

$$\gamma_{ACE}^2 = \max\left\{\frac{S_{rare}}{C_{ACE}} \frac{\sum_{i=1}^{10} i(i-1)F_i}{(N_{rare})(N_{rare}-1)} - 1\right\}$$

To use both estimators in EstimateS, the data need to be organized as a matrix, where rows and columns can represent the samples and the species interchangeably; it is necessary to establish the order once the program has started. Once several randomizations are performed (100 in our case) the final value of the estimator is obtained and we can graph the results as curves (Gotelli & Colwell 2001). The number of sampling events is presented on the X-axis, and the number of species on the Y-axis. Thus, the S_{est} (number of species estimated by the estimator) and the S_{obs} (number of species observed) can be compared. When you have the total number of sampling events, there is some separation between the S_{est} and the S_{obs} curve. That separation indicates how many species are missing to register in that habitat. The more separated the curves are, more species we could expect that are missing from our survey. With this information it is possible to evaluate how efficient was the registration of herpetofauna, in terms of "completeness", by determining what percentage represents the observed fauna, in relation to the estimated fauna (Moreno & Halffter 2000). To facilitate the data analysis, transects, free search periods and inspection of the pitfall traps within the same habitat carried out in one day were grouped in "Sampling Events".

Diversity indices and some parameters were calculated using PAST Software Version 4.0. A "diversity index" is a single statistic that incorporates information on richness and evenness. Shannon-Wiener (H´) and Simpson (1-D) diversity indices were used, due to their different sensitivity to the two components of alpha diversity, being Shannon-Wiener index more sensitive to rare species, and Simpson´s index more sensitive to changes in abundance of the most common species (Magurran 2004).

Shannon-Wiener index assumes that individuals are randomly sampled from an infinitely large community and that all species are represented in the sample. This index quantifies the uncertainty in predicting the species identity of an individual that is taken at random from the dataset (Jost 2006):

$$H' = -\sum p_i \ln p_i$$

The quantity pi is the proportion of individuals found in the ith species.

Simpson´s index gives the probability of any two individuals drawn at random from an infinitely large community belonging to the same species (Simpson 1949):

$$D = \sum p_i^2$$

Where p_i is the proportion of individuals in the ith species. The form of the index appropriate for a finite community is:

$$D = \sum \left(\frac{n_{i[n_i - 1]}}{N[N-1]} \right)$$

Where n_i is the number of individuals in the ith species; and N is the total number of individuals.

As D increases, diversity decreases. Simpson´s index is therefore expressed as “1-D”. Simpson´s index is heavily weighted towards the most abundant species in the sample, while being less sensitive to species richness. This index captures the variance of the species abundance distribution (Magurran 2004).

However, we must be prudent with respect to the use of diversity indices, as they can be expressed in different units, and therefore their values are difficult to interpret. For example, the Shannon index is expressed in units called *nats*, when the base of the logarithm used is *e*; in *bits*, when the base is 2; or in *decits*, when the base is 10 (Tuomisto 2010). On the other hand, the indices do not fulfil some mathematical principles inherent to the concept of diversity, such as the “replication principle”. This principle says that if we have “N” equally large, equally diverse sets with no species in common, the diversity of the pooled sets must equal N times the diversity of a single set (Jost 2010). Some authors defend the use of measures that fulfil the expected properties of the concept of diversity, enhancing the use of the “effective number” to interpret and compare different values of Shannon-Wiener index (Jost 2006). The “effective number” is a useful measure that provides the number of species that would have been found if the sample had all species been equally common (Hill 1973).

$$\textit{Effective number for Shannon-Wiener index} = e^{H'}$$

Jaccard´s similarity index were calculated and represented as hierarchical cluster in order to check how similar the different habitats are to each other. This index considers the similarity between two sets (in our case, habitats) of attributes (in our case, species) as the number of attributes shared divided by the total number of attributes present in either of them (Real 1999). Jaccard´s index may be expressed as:

$$J = C/(A + B - C)$$

Where A is the number of attributes presents in the set “a”, B is the number of attributes presents in the set “b”, and C is the number of attributes present in both sets.

4. Results

4.1. Species Inventory and Conservation Status

After 64 days of field work we managed to record 31 species. Together with the data collected by Theart et al. (unpublished), we get a total number of 41 different species in the area (Table 1).

Table 1. Reptile species recorded in KumKum and Pelgrimrust by Theart (2018) and during this study (2019). Conservation status is indicated attending to SARCA and IUCN assessments. G: Global assessment; R: Regional assessment; X: recorded; (-): non-recorded/non-assessed species.

Scientific Name	Common Name	Theart 2018	Study 2019	SARCA 2009	IUCN 2020
Testudinidae					
Psammobates tentorius ver.	Tent Tortoise	X	(-)	LC (G)	NT (G)
Gekkonidae					
Chondrodactylus angulifer	Giant Ground Gecko	X	X	LC (R)	LC (G)
Chondrodactylus bibronii	Bibron´s Tubercled Gecko	X	X	LC (G)	(-)
Goggia lineata	Striped Dwarf leaf-toed Gecko	X	X	LC (G)	LC (G)
Lygodactylus bradfieldi	Bradfield´s Dwarf Gecko	X	X	LC (R)	(-)
Pachydactylus atorquatus	Augrabies Gecko	X	(-)	LC (G)	LC (G)
Pachydactylus haackei	Haacke´s Gecko	X	(-)	LC (G)	(-)
Pachydactylus montanus	Namaqua Mountain Gecko	X	X	LC (G)	(-)
Pachydactylus punctatus	Speckled Gecko	X	X	LC (R)	(-)
Pachydactylus rugosus	Rough Gecko	(-)	X	LC (R)	(-)
Ptenopus garrulus mac.	Common Barking Gecko	X	X	LC (G)	(-)
Agamidae					
Agama aculeate	Ground Agama	(-)	X	LC (G)	(-)
Agama anchietae	Anchieta´s Agama	(-)	X	LC (R)	(-)
Agama atra	Southern Rock Agama	X	X	LC (G)	LC (G)

Table 1. (Continued)

Scientific Name	Common Name	Theart 2018	Study 2019	SARCA 2009	IUCN 2020
Lacertidae					
Meroles suborbitalis	Spotted Desert Lizard	(-)	X	LC (R)	(-)
Nucras tessellata	Western Sandveld Lizard	(-)	X	LC (G)	(-)
Pedioplanis inornata	Plain Sand Lizard	X	X	LC (R)	(-)
Pedioplanis lineoocellata	Spotted Sand Lizard	(-)	X	LC (G)	(-)
Pedioplanis namaquensis	Namaqua Sand Lizard	X	X	LC (R)	(-)
Cordylidae					
Karusasaurus polyzonus	Karoo Girdled Lizard	X	(-)	LC (G)	LC (G)
Platysaurus attenboroughi	Attenborough´s Flat Lizard	X	X	(-)	LC (G)
Gerrhosauridae					
Cordylosaurus subtessellatus	Dwarf Plated Lizard	X	X	LC (G)	LC (G)
Scincidae					
Acontias tristis	Namaqualand Legless Skink	X	X	LC (G)	LC (G)
Trachylepis occidentalis	Western Three-striped Skink	X	X	LC (R)	(-)
Trachylepis sulcata	Western Rock Skink	X	X	LC (R)	(-)
Trachylepis variegata	Variegated Skink	X	X	LC (R)	(-)
Colubridae					
Dasypeltis scabra	Rhombic Egg-eater	X	(-)	LC (R)	LC (G)
Telescopus beetzi	Beetz´s Tiger Snake	(-)	X	LC (G)	(-)
Elapidae					
Aspidelaps lubricus	Coral Shield-cobra	X	(-)	LC (G)	(-)
Naja nigricincta woodi	Black Spitting Cobra	X	(-)	LC (R)	(-)
Naja nivea	Cape Cobra	X	X	LC (R)	(-)

Table 1. (Continued)

Scientific Name	Common Name	Theart 2018	Study 2019	SARCA 2009	IUCN 2020
Lamprophiidae					
Boaedon capensis	Brown House Snake	X	(-)	LC (R)	(-)
Prosymna frontalis	SW African Shovel-snout	X	X	LC (G)	(-)
Psammophis notostictus	Karoo Whip Snake	X	X	LC (R)	(-)
Psammophis trigrammus	Western Whip Snake	(-)	X	LC (G)	(-)
Psammophis trinasalis	Fork-marked Whip Snake	X	(-)	LC (R)	(-)
Viperidae					
Bitis arietans	Puff Adder	X	(-)	LC (R)	(-)
Bitis caudalis	Horned Adder	X	X	LC (R)	(-)
Bitis xeropaga	Desert Mountain Adder	X	X	LC (G)	(-)
Leptotyphlopidae					
Namibiana occidentalis	Western Worm Snake	(-)	X	LC (G)	(-)
Typhlopidae					
Rhinotyphlops lalandei	Delalande´s Beaked Blind Snake	(-)	X	LC (R)	(-)

Only 10 of the 41 species recorded in the area have been assessed by the IUCN. However, all species except *Platysaurus attenboroughi* were assessed by the SARCA project.

4.2. Species per Habitat

A total of 287 transects were carried out in the different habitats of the study area (see Appendix 1) and a total of 522 individuals were recorded, including those found in "anthropic" habitat (see Appendix 2). The total number of individuals found in riverbed, mountain, sandy and rocky plain habitat is 450. The number of individuals of each species per habitat can be checked in Table 2.

Table 2. Number of individuals of each species per habitat. M: mountain; R: riverbed; SP: sandy plain; RP: rocky plain; A: anthropic. (-): non-recorded.

Scientific Name	Common Name	M	R	SP	RP	A
Gekkonidae						
Chondrodactylus angulifer	Giant Ground Gecko	(-)	(-)	11	3	(-)
Chondrodactylus bibronii	Bibron´s Tubercled Gecko	11	12	13	7	34
Goggia lineata	Striped Dwarf Leaf-toed Gecko	(-)	(-)	2	(-)	(-)
Lygodactylus bradfieldi	Bradfield´s Dwarf Gecko	(-)	(-)	9	3	2
Pachydactylus montanus	Namaqua Mountain Gecko	47	6	5	24	8
Pachydactylus punctatus	Speckled Gecko	(-)	(-)	1	(-)	(-)
Pachydactylus rugosus	Rough Gecko	(-)	(-)	2	(-)	(-)
Ptenopus garrulus	Common Barking Gecko	(-)	2	13	2	(-)
Agamidae						
Agama aculeate	Ground Agama	1	(-)	(-)	(-)	(-)
Agama anchietae	Anchieta´s Agama	1	2	1	(-)	1
Agama atra	Southern Rock Agama	(-)	(-)	(-)	(-)	1
Lacertidae						
Meroles suborbitalis	Spotted Desert Lizard	(-)	(-)	25	1	(-)
Nucras tessellata	Western Sandveld Lizard	1	(-)	(-)	(-)	(-)
Pedioplanis inornata	Plain Sand Lizard	25	9	7	17	(-)
Pedioplanis lineoocellata	Spotted Sand Lizard	(-)	(-)	1	2	(-)
Pedioplanis namaquensis	Namaqua Sand Lizard	(-)	(-)	2	3	(-)
Cordylidae						
Platysaurus attenboroughi	Attenborough´s Flat Lizard	1	(-)	(-)	(-)	(-)
Gerrhosauridae						
Cordylosaurus subtessellatus	Dwarf Plated Lizard	3	(-)	(-)	(-)	(-)

Table 2. (Continued)

Scientific Name	Common Name	M	R	SP	RP	A
Scincidae						
Acontias tristis	Namaqualand Legless Skink	(-)	(-)	3	(-)	(-)
Trachylepis occidentalis	Western Three-striped Skink	1	(-)	(-)	(-)	2
Trachylepis sulcata	Western Rock Skink	26	32	11	15	6
Trachylepis variegata	Variegated Skink	16	24	5	24	13
Colubridae						
Telescopus beetzi	Beetz´s Tiger Snake	(-)	(-)	1	(-)	(-)
Elapidae						
Naja nivea	Cape Cobra	(-)	(-)	1	(-)	(-)
Lamprophiidae						
Prosymna frontalis	SW African Shovel-snout	(-)	2	(-)	(-)	(-)
Psammophis notostictus	Karoo Whip Snake	(-)	(-)	1	(-)	1
Psammophis trigrammus	Western Whip Snake	1	(-)	(-)	(-)	(-)
Viperidae						
Bitis caudalis	Horned Adder	3	1	3	(-)	1
Bitis xeropaga	Desert Mountain Adder	1	(-)	(-)	(-)	(-)
Leptotyphlopidae						
Namibiana occidentalis	Western Worm Snake	(-)	2	(-)	(-)	1
Typhlopidae						
Rhinotyphlops lalandei	Delalande´s Beaked Blind Snake	1	1	(-)	(-)	1
TOTAL		139	93	117	101	72

A photographic catalogue of the species recorded and habitat preferences according to the literature can be consulted on Appendix 3.

The total number of species recorded in each habitat; and the number of species recorded for the different combinations of habitats are represented in Figures 6 and 7, respectively. Note that in both cases, mountain and sandy plain habitats stand out.

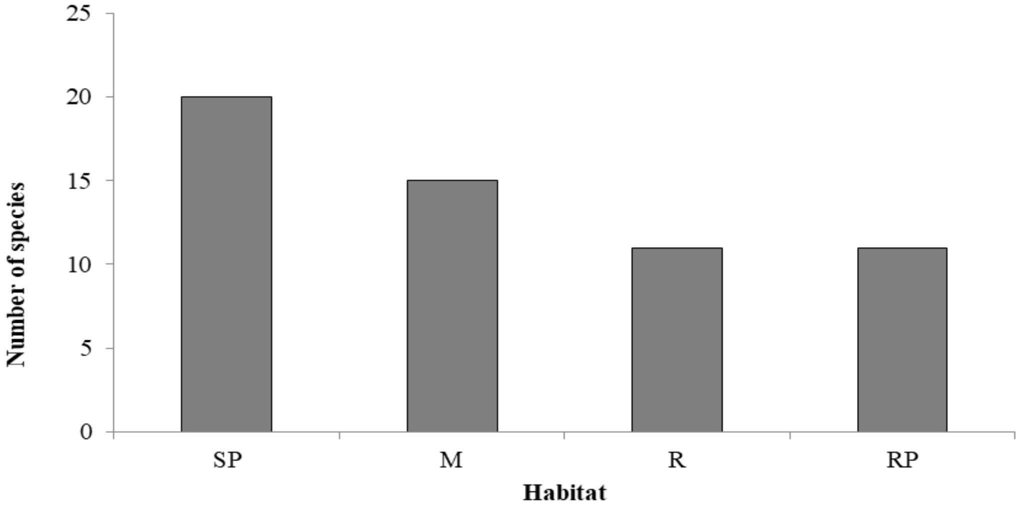

Figure 6. Number of species registered per habitat in the study area. SP: sandy plain; M: mountain; R: riverbed; RP: rocky plain.

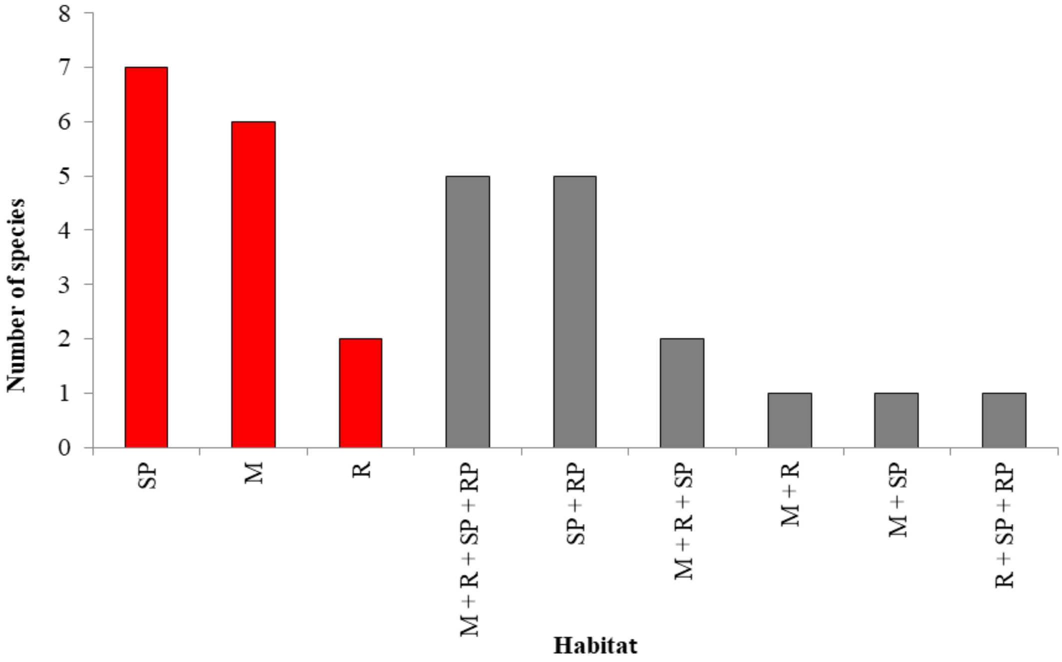

Figure 7. Total number of species registered for the different combinations of habitats. SP: sandy plain; M: mountain; R: riverbed; RP: rocky plain. Red bars indicate the number of habitat-specialist species. Grey bars indicate the number of habitat-generalist species.

In the case of mountain habitat the most abundant species was *Pachydactylus montanus*, with almost twice as many individuals as the next species in the abundance ranking (Figure 8). The large difference in the number of *Pachydactylus montanus* individuals compared to the rest of species makes the family Gekkonidae the most abundant in this habitat (Figure 9).

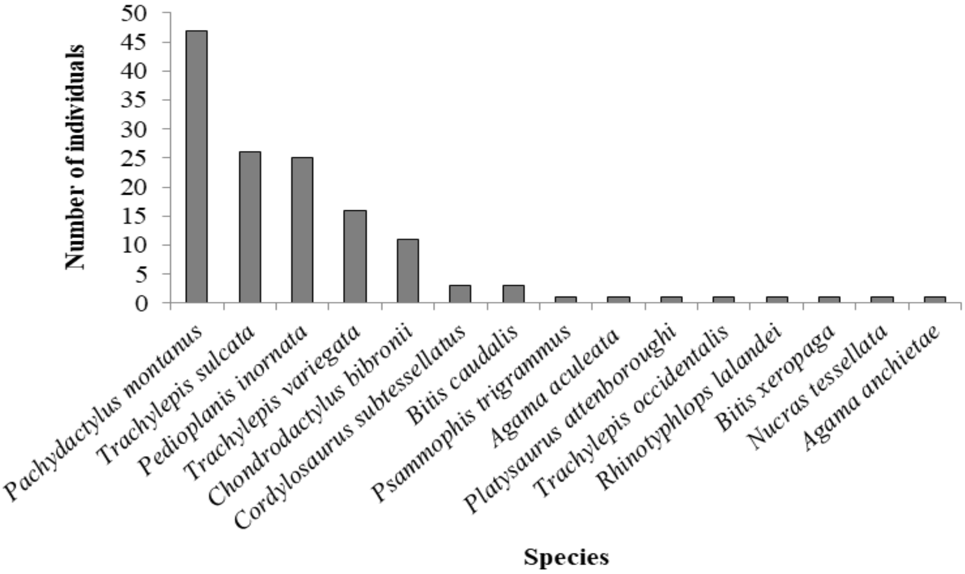

Figure 8. Number of individuals of each species recorded in mountain habitat, ranked from the most abundant to the scarcest.

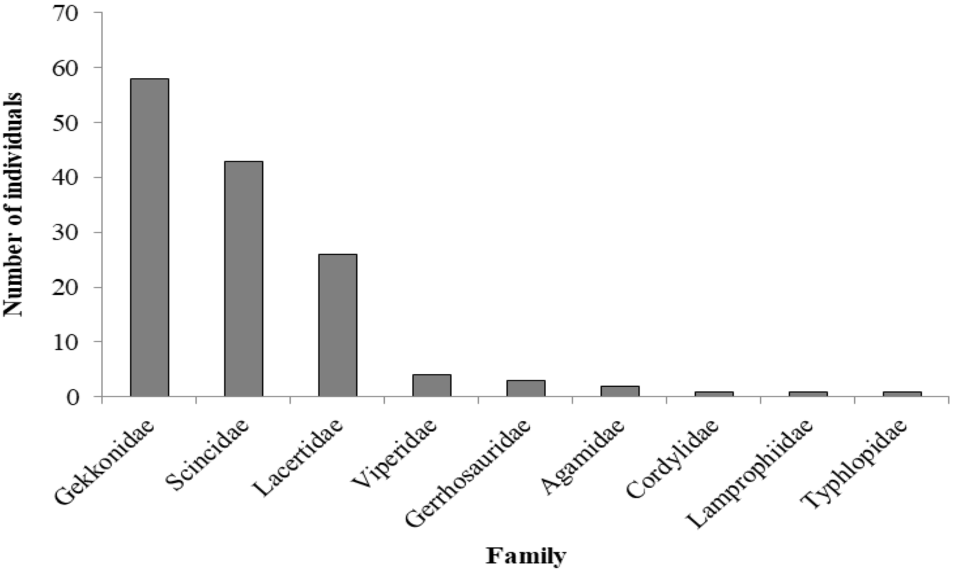

Figure 9. Number of individuals of each family recorded in mountain habitat, ranked from the most abundant to the scarcest.

In riverbed habitat the most abundant species were *Trachylepis sulcata* and *Trachylepis variegata* (Figure 10), making the family Scincidae the most abundant in this habitat (Figure 11).

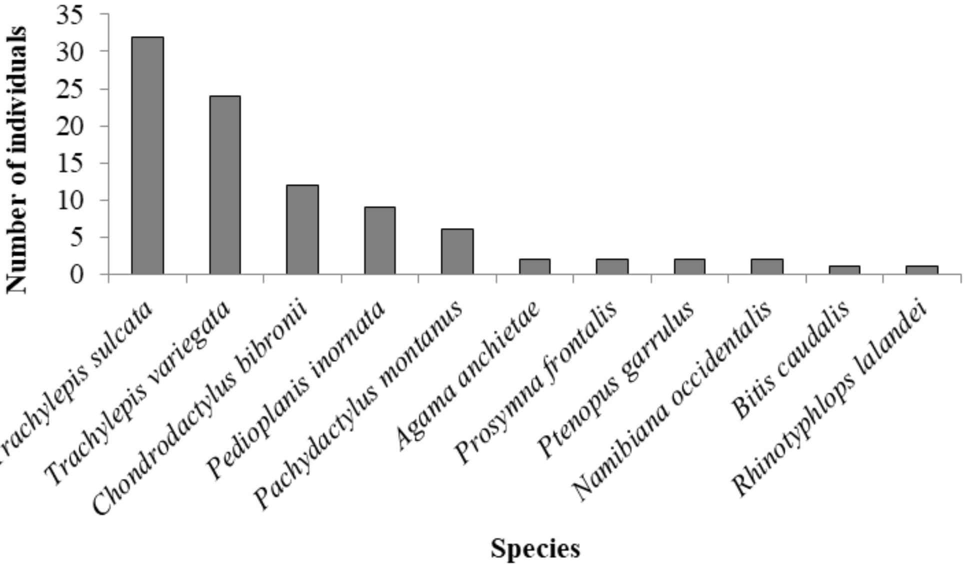

Figure 10. Number of individuals of each species recorded in riverbed habitat, ranked from the most abundant to the scarcest.

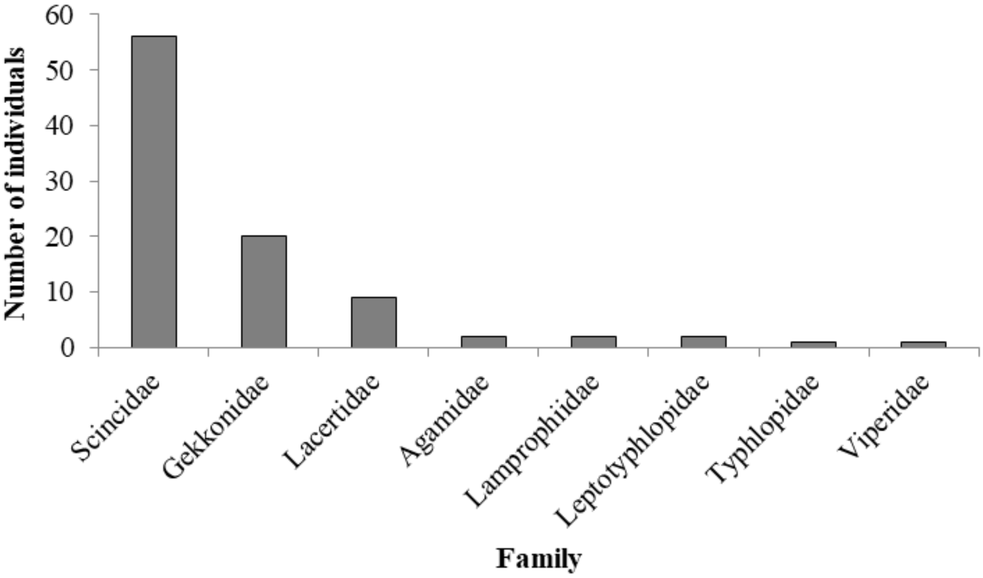

Figure 11. Number of individuals of each family recorded in riverbed habitat, ranked from the most abundant to the scarcest.

The most abundant species in sandy plain habitat was *Meroles suborbitalis*, belonging to Lacertidae family (Figure 12). However, the sum of individuals of species in the family Gekkonidae is greater, so this is the most abundant family in this habitat (Figure 13).

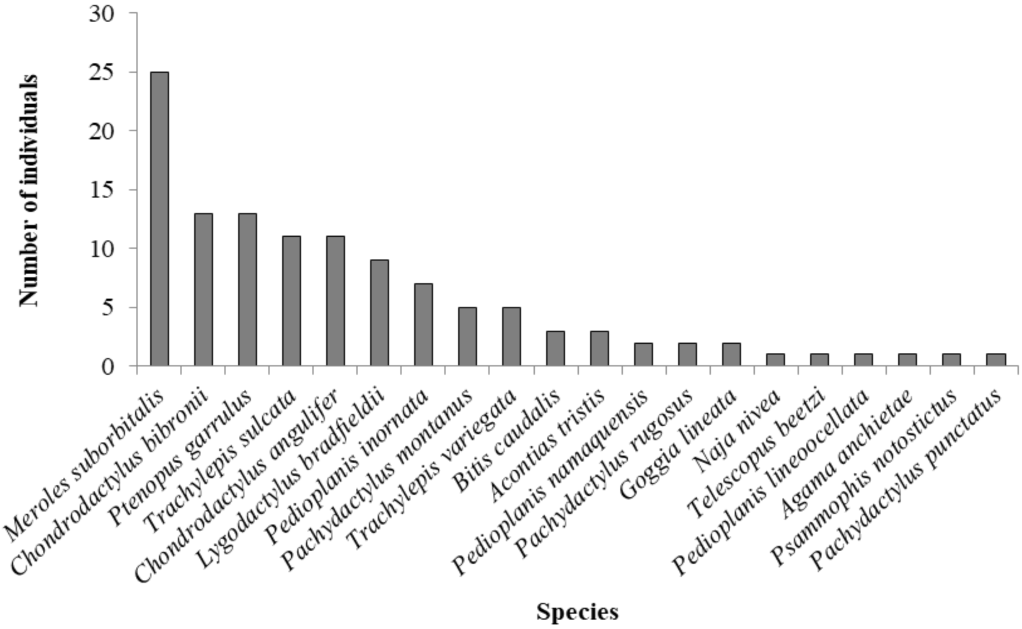

Figure 12. Number of individuals of each species recorded in sandy plain habitat, ranked from the most abundant to the scarcest.

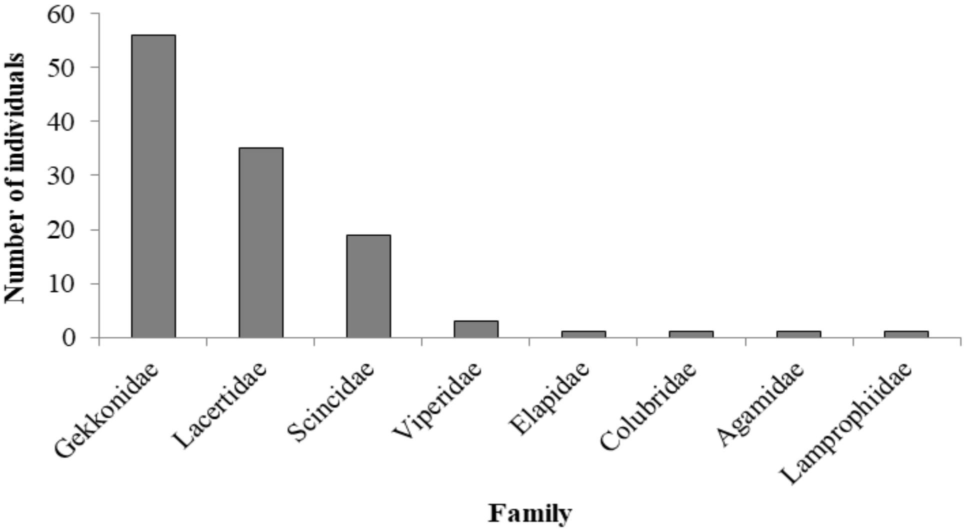

Figure 13. Number of individuals of each family recorded in sandy plain habitat, ranked from the most abundant to the scarcest.

In rocky plain habitat the most abundant species were *Pachydactylus montanus* and *Trachylepis variegata*, belonging to Gekkonidae and Scincidae families respectively (Figure 14), being both families equally abundant (Figure 15).

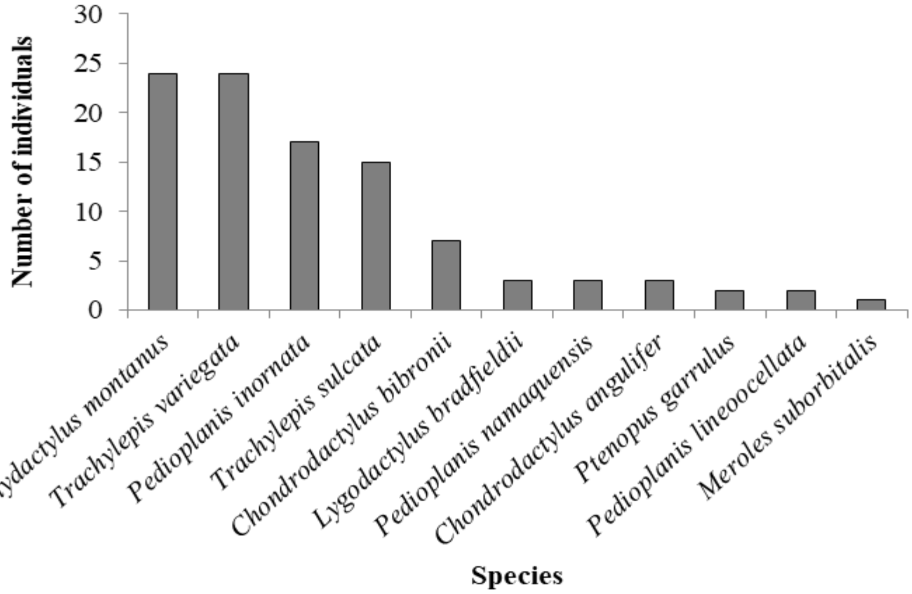

Figure 14. Number of individuals of each species recorded in rocky plain habitat, ranked from the most abundant to the scarcest.

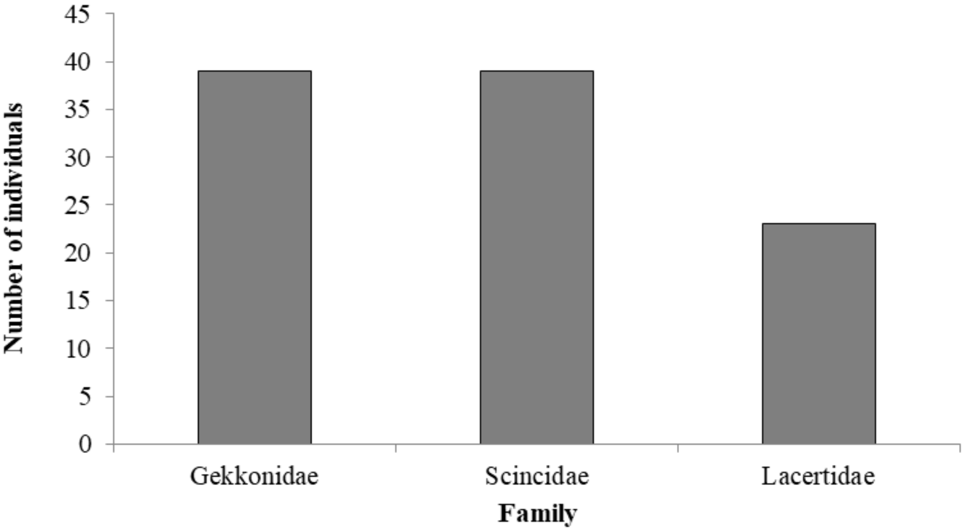

Figure 15. Number of individuals of each family recorded in rocky plain habitat, ranked from the most abundant to the scarcest.

The most abundant species in the full study area were *Pachydactylus montanus* and *Trachylepis sulcata*, belonging to Gekkonidae and Scincidae families respectively (Figure 16), being the most abundant families in the area (Figure 17).

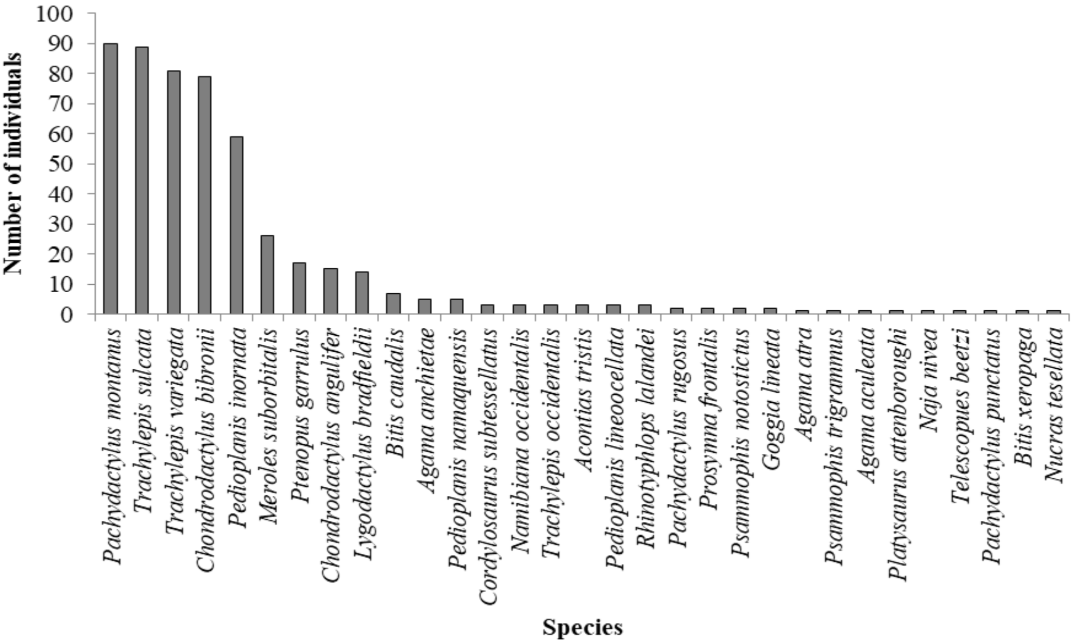

Figure 16. Number of individuals of each species recorded in the study area, ranked from the most abundant to the scarcest. Including mountain, riverbed, sandy plain, rocky plain and anthropic habitats.

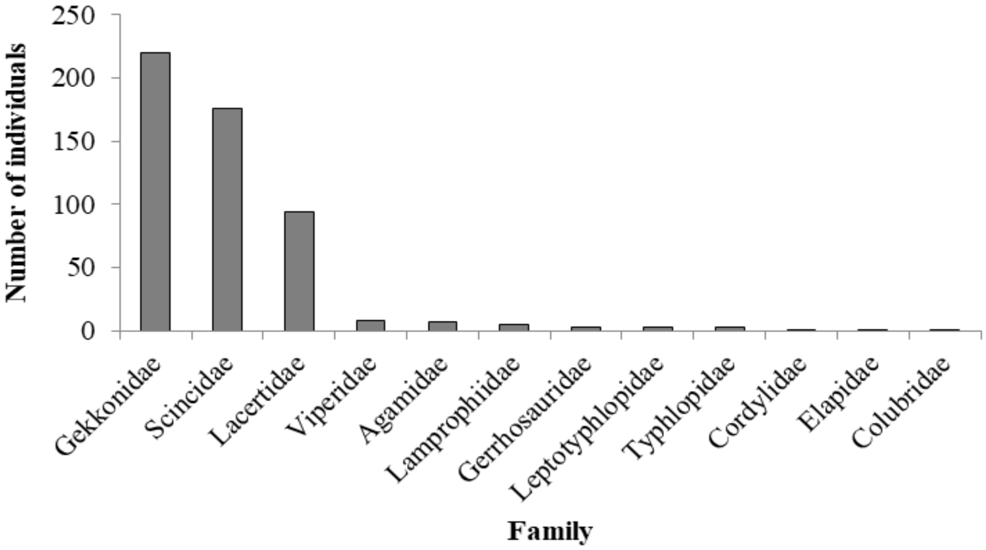

Figure 17. Number of individuals of each family recorded in the study area, ranked from the most abundant to the scarcest. Including mountain, riverbed, sandy plain, rocky plain and anthropic habitats.

4.3. Rarefaction Curves and Estimates of Species Richness

The actual number of species detected in the mountain habitat was much lower than the number of species estimated by Chao1 and ACE (Figure 18). This difference gives us a sampling efficiency of 35.0 % according to Chao1 and 39.0 % according to ACE, note that the estimator curves do not stabilize. However, the sampling efficiency in riverbed is 95.7 % and 84.6 % for Chao1 and ACE respectively, with the curves stabilized for both estimators (see Figure 19).

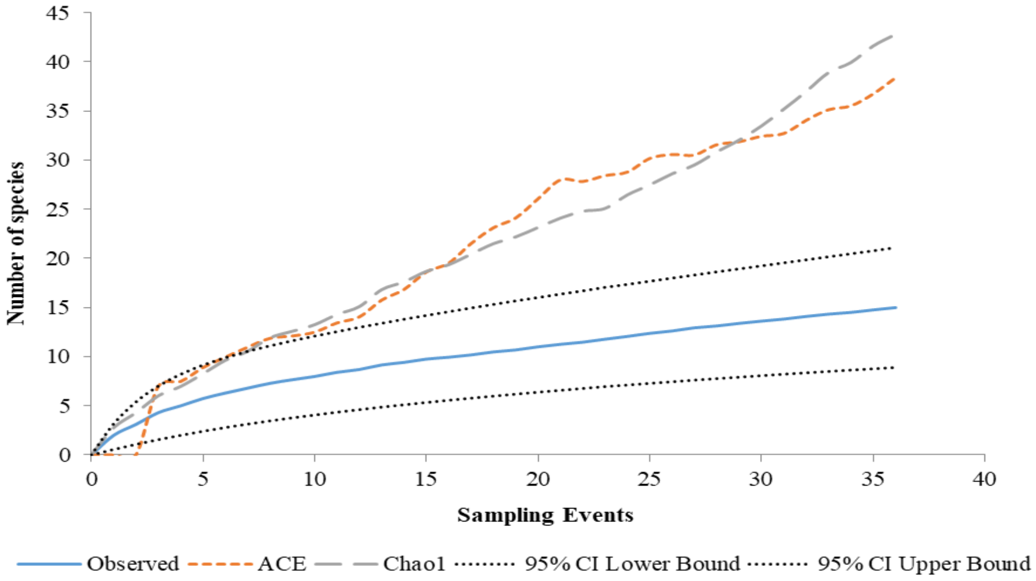

Figure 18. Sample-based rarefaction curve and estimates of species richness for mountain habitat.

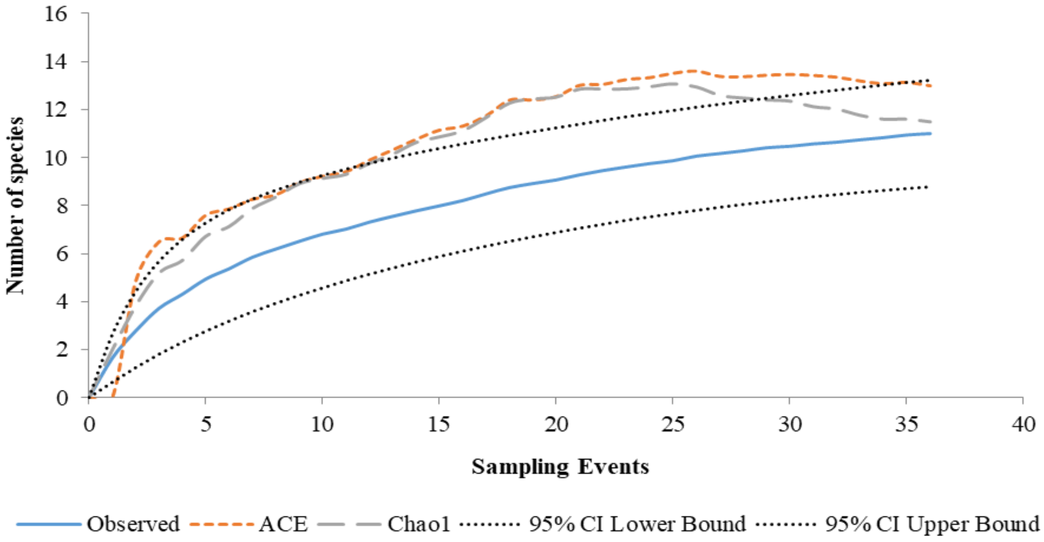

Figure 19. Sample-based rarefaction curve and estimates of species richness for riverbed habitat.

The sampling efficiency in sandy plain is 77.0 % and 75.8 % for Chao1 and ACE respectively (see Figure 20). As shown in Figure 21, the number of real species detected in rocky plain habitat was very close to the number of species estimated by Chao1 and ACE. This small difference means a sampling efficiency of 97.7 % according to Chao1 and 95.8 % according to ACE.

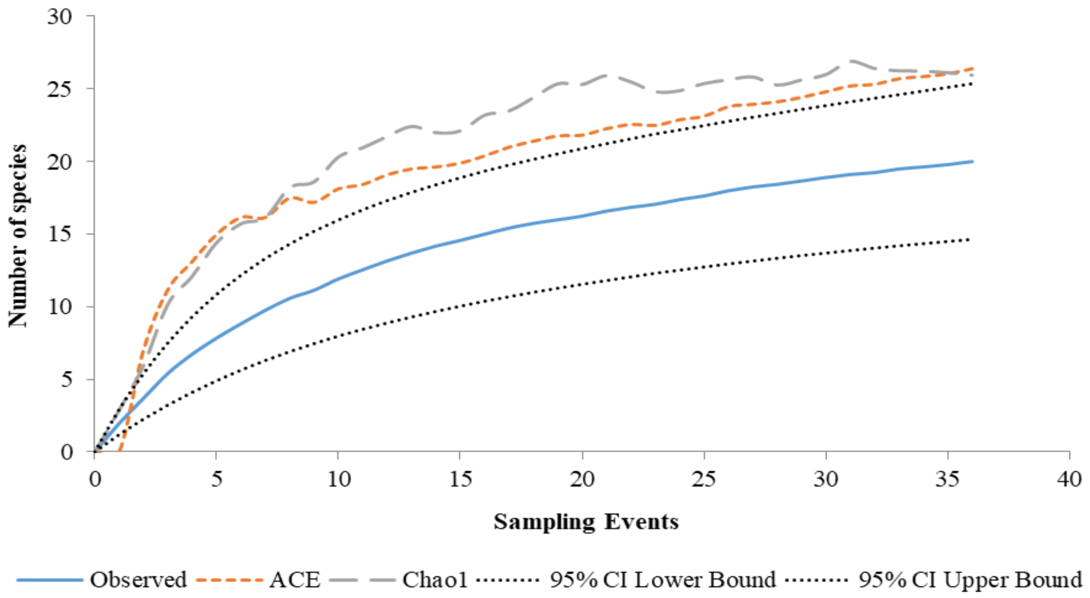

Figure 20. Sample-based rarefaction curve and estimates of species richness for sandy plain habitat.

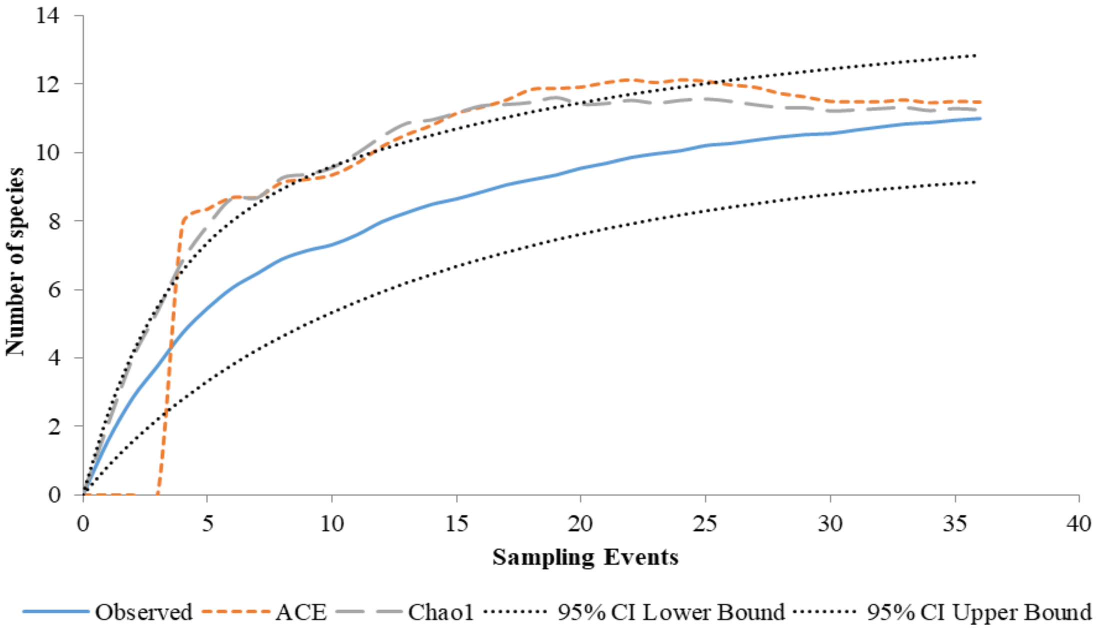

Figure 21. Sample-based rarefaction curve and estimates of species richness for rocky plain habitat.

Overall, the sampling efficiency for the study area is 75.0 % and 73.1 % for Chao1 and ACE respectively (see Figure 22). The total number of species for the study area according to the estimators is 40 or 41 species.

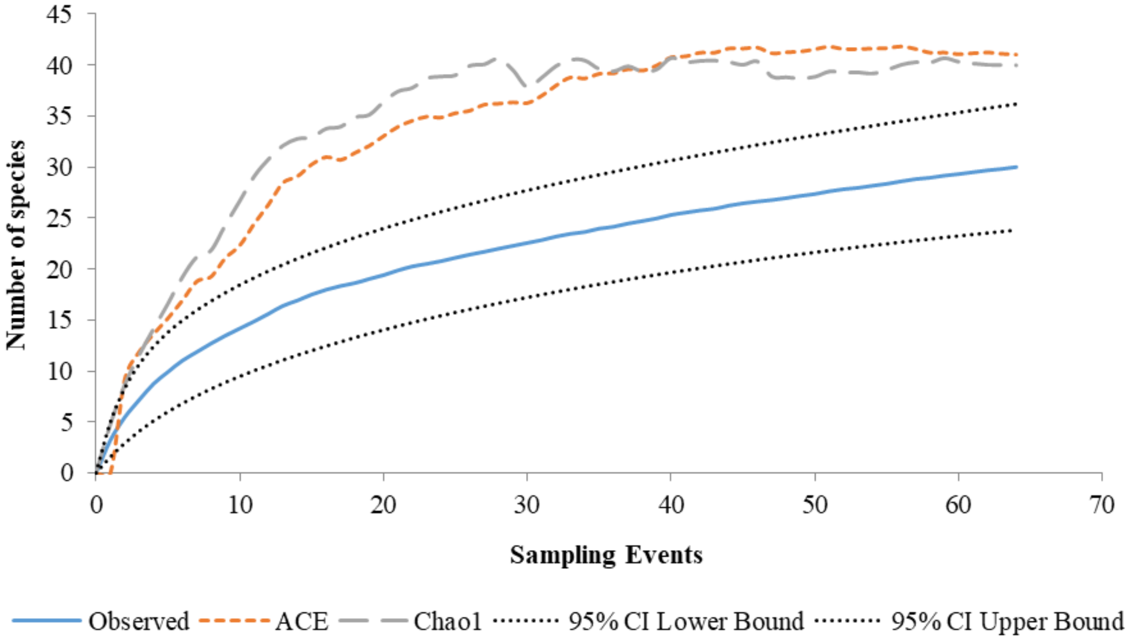

Figure 22. Sample-based rarefaction curve and estimates of species richness for the study area.

4.4. Biodiversity and Similarity

The results obtained for the diversity indices and for the effective numbers are shown in the table. Note that the values for the sandy plain stand out (Table 3).

Table 3. Result of the diversity indices and effective number for the different habitats in the study area, the number of species and individuals recorded in each habitat is also indicated.

	Mountain	Riverbed	Sandy Plain	Rocky Plain
Number of recorded species	15	11	20	11
Total number of individuals	139	93	117	101
Simpson Index (1-D)	0.798	0.783	0.896	0.828
Shannon Index (H)	1.888	1.811	2.539	1.965
Effective number (e^H)	6.606	6.117	12.667	7.135

The similarity indices reflect a greater similarity between plain habitats with respect to riverbed and mountain, which in turn show some similarity (Table 4).

Table 4. Results of the Jaccard´s similarity index that reflect the level of similarity between the different habitats of the study area.

	Mountain	**Riverbed**	**Sandy Plain**	**Rocky Plain**
Mountain	1	0.44	0.25	0.24
Riverbed	-	1	0.35	0.37
Sandy Plain	-	-	1	0.55
Rocky Plain	-	-	-	1

When these data are displayed as a hierarchical cluster, two sets are revealed, one consisting of sandy plain and rocky plain; and the other consisting of mountain and riverbed (Figure 23).

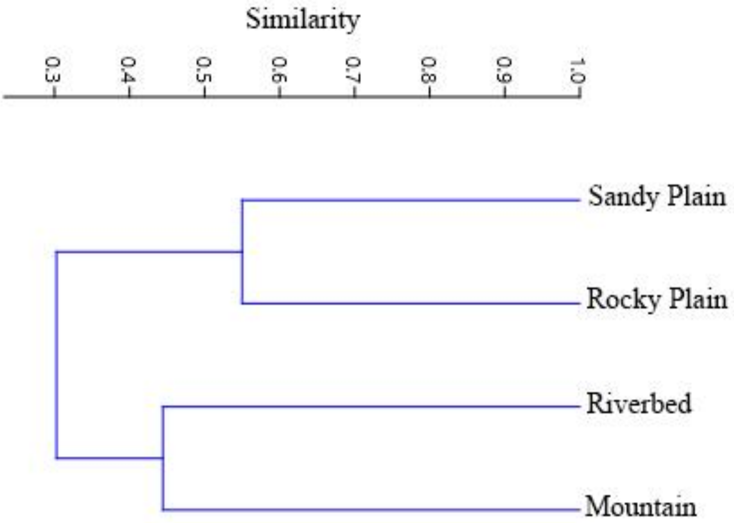

Figure 23. Hierarchical cluster showing the similarity sets of the different habitats in the study area.

5. Discussion

During our fieldwork we were able to record 31 species distributed among the different habitats of our study area. Of the species recorded 15 were found only in one of the natural habitats (not considering Anthropic), being considered specialists, the rest of species were found in at least two habitats, being considered generalists. Most of these species lack an IUCN assessment, although all except *Platysaurus attenboroughi* were assessed by the SARCA project. The survey has been characterized by a considerable number of species belonging to the families Gekkonidae and Lacertidae, although in number of individuals Scincidae stands out over Lacertidae. The efficiency of our sampling has been variable depending on the habitat we consider, from 35.0 % efficiency in mountain to 97.7 % in rocky plain, with an overall efficiency for the whole study area of 75.0 %. After calculating the diversity indices and effective numbers for the different habitats we observe that sandy plain habitat stands out, having an effective number that doubles the value of the rest of the habitats, and therefore being able to attribute to sandy plain twice the diversity of the rest of the habitats. The results of the Jaccard index reflect higher similarity between sandy plain and rocky plain than between the other habitats.

We present an updated inventory of the reptile species recorded in the private areas of KumKum and Pelgrimrust, adding 10 new species to the inventory previously elaborated by Theart et al. (unpublished), obtaining a total of 41 reptile species in the study area, a high diversity. However, it is important to note that a community generally consists of a considerable number of species with different abundances, so some rare species in the community may not be represented in our inventory because the sampling effort invested was insufficient to record all species. Since the number of reptile species in Namibia currently stands at 276, our study area represents at least 15 % of the total species in the country, a considerable percentage. On the other hand, the total number of specimens recorded was relatively low, only 522 individuals during the 64 days of sampling. This is consistent with the observation made by Theart et al. (unpublished) that the abundance of reptiles is relatively low compared to similar habitats south of the Orange River, in South Africa. A possible explanation for the high species diversity in the study area could be found in its topographic heterogeneity, one of the environmental factors driving species richness according to Engemann et al. (2015), who state that high topographic complexity promotes habitat diversity and greater species richness.

The habitat with the highest number of species recorded was sandy plain, with 20 species, followed by mountain, with 15 species, and riverbed and rocky plain, with 11 species each. Considering that the sum of these numbers is greater than 31, the total number of species recorded during our sampling, it is easy to deduce that many of the recorded species had generalist behaviour, opting for more than one type of habitat. However, to correctly interpret these data it is necessary to take into account the number of individuals of each species present in the different habitats and certain ecological and behavioural aspects of the recorded species.

The species found exclusively in one habitat were represented by very low numbers of individuals, so the categorization of these species as specialists should be treated with caution. For example, the 2 individuals of *Goggia lineata* found in the study area were on dry vegetation in a sandy plain, although the preferred habitat for this species consists of small rock outcrops and rock piles with low vegetation cover (Branch et al. 1995). It is probable that the small size of this species together with its cryptic colour made it difficult for us to detect it in other habitats in the study area in line with what is mentioned in the literature. Both individuals were detected during the night while we were inspecting small bushes, the light from the head torches made them turn pale, standing out among the dead vegetation. Other species such as *Pachydactylus rugosus* and *Naja nivea* are considered highly generalist by the literature, to the extent that they can be found in human settlements (Bates et al. 2014). This plasticity invites us to think that the fact that we found these species only in sandy plain habitat could be a coincidence, being viable their presence also in other habitats of the study area. On the other hand, the finding of some species in a certain type of habitat, even if they were only a few individuals, is completely in line with what is expected according to the literature. This is the case of *Platysaurus attenboroughi* and *Bitis xeropaga* among others, species with a marked preference for rocky outcrops, so their presence in mountain habitat was to be expected (Branch 1998; Weeber et al. 2018).

The species recorded exclusively in riverbed habitat have several characteristics in common: (1) they are snakes, (2) they have fossorial habits, (3) their period of activity is nocturnal, and (4) at least one individual of each species were caught in pitfall traps. *Prosymna frontalis* is a species that prefers rocky habitats although with fossorial tendencies (Branch 1998). This is consistent with our findings, since both individuals were found in riverbeds surrounded by rocky plains and slow rocky hills. *Namibiana occidentalis* is a species considered strictly fossorial (Bates et al. 2014), living in non-compacted sandy substrates, and therefore is difficult to detect. According to the literature, this species only emerges to the surface during the night after heavy rains (Marais 2004), which did not happen during our stay in KumKum, where two individuals were caught in pitfall traps, so perhaps the frequency with which *N. occidentalis* emerges to the surface during the night is greater than is thought. A third individual of this species was sighted for a few consecutive nights moving around the house in KumKum area, which is located next to a riverbed. As can be inferred, the categorization of habitat specialist depends on the species and habitat to be considered, keeping in mind that the number of individuals of these species is extremely low to make any designation that contradicts what has been collected in the available literature.

For species found in more than one habitat, “generalists”, certain trends can be observed depending on the species. Most individuals of *Chondrodactylus angulifer*, *Ptenopus garrulous* and *Meroles suborbitalis* were found in sandy plain, which is logical considering that these species build burrows of relatively important depth (Alexander & Marais 2007), for which they need a substrate with greater compaction than the sand present in riverbed habitat. *Lygodactylus bradfieldi* has also been recorded more frequently in sandy plain, although this data should be analysed with caution. Of the 14 recorded individuals of *L. bradfieldi* 12 were found associated with shrubs belonging to the genus *Boscia*, the remaining 2 individuals were found on ornamental plants in anthropogenic habitat. This raises several questions: (1) is there a relationship between *L. bradfieldi* and shrubs of the genus *Boscia* or is the detectability of this species facilitated by contrasting its pattern with the pale trunk of the plant? If there is a relationship between the two species, is it influenced by the habitat in which the plant is found? Perhaps we find more individuals of *L. bradfieldi* in sandy plain just because in this habitat *Boscia* is more frequent. The literature consulted suggests certain preference for trees of the genus *Acacia*, although it defines *L. bradfieldi* as a generalist species that can inhabit both rocky environments and sandy areas with dispersed vegetation, sometimes even buildings (Branch 1998; Alexander & Marais 2007; Bates et al. 2014). *Pachydactylus montanus* has a high tendency to inhabit rocky habitats (Alexander &

Marais 2007), this gecko was one of the most abundant species in the study area with 90 individuals; 47 of the found individuals were recorded in mountain and 24 in rocky plain, with the individuals recorded in riverbed, sandy plain and anthropic being minimal in numbers.

The only species more frequent in Anthropic habitat than in natural habitats was *Chondrodactylus bibronii*, this phenomenon is consistent with those exposed by Branch (1998) about the tendency of this species to form large colonies that sometimes establish in isolated buildings. The reasons underlying these congregations in human constructions have been determined as a high availability of shelters that provide good environmental conditions, less probability of being hunted by predators and great presence of potential prey attracted by light sources (Meyer & Mouton 2007; Perry et al. 2008).

The families with higher species richness and abundance of individuals were Gekkonidae, Lacertidae and Scincidae, reflecting the radiations of these families in many regions of southern Africa (Bauer 1999; Herrmann & Branch 2013). On the other hand, snakes were not very abundant, both in species richness by family and in number of individuals. According to How (1998), snakes generally are infrequently registered during herpetofaunal surveys, so their true representation in reptile assemblages is often underestimated by short-term sampling surveys. This is clearly demonstrated in the data compiled in Thompson et al. (2003), where snakes reach their highest proportion in assemblages in studies that have the longest temporal span.

Both estimators showed a sampling efficiency minimum for mountain, 35.0 %, and maximum for rocky plain, 97.7 %. Of these, Chao1 tends to show more faithful results since it obtains minimum estimates (Magurran 2004), and it also works better when most of the information is concentrated in low numbers of abundance, for example when most of the species in the samples are observed as "singletons" or "doubletons" (Coddington et al. 1996). Mountain was the only habitat with a sampling efficiency of less than 75.0 %, it is also the only habitat for which the estimator curves did not reach the asymptote. This may be because the sampling effort in this habitat was not high enough or because the methods used were not adequate (Magurran 2004), although according to Kurniati (2005) elevation is one of barrier factors to herpetofauna distribution so species richness of reptiles decline with increasing elevation. The overall sampling efficiency for the Protected Area is 75.0 % with the curves of both estimators stabilized for values of 40-41 species, which is in fact the number of species present in the study area taking into account those recorded by Francois et al. (unpublished) and those recorded in this study. For Zakaria et al. (2019) a sampling efficiency of reptile surveys greater than 70.0 % is acceptable. However, there is controversy depending on which taxonomic group we are considering; Moreno and Halffter (2000), analysing bat diversity, consider that a sampling efficiency of less than 90.0 % reveals that the survey was not exhaustive enough.

The results of Shannon-Wiener, Simpson, Jaccard indices and the Effective Numbers reflect a diversity of reptiles in sandy plain that is remarkable with respect to other habitats, as well as a certain degree of similarity between this habitat and rocky plain. This could simply be due to the way the different habitats are distributed in the study area, with large patches of sandy plain and rocky plain alternating in the protected area; and with riverbeds running mainly between mountainous areas. However, given the low numbers of individuals found for many of the species recorded, it is difficult to interpret these results in depth. Long-term studies are needed to record a greater number of individuals of the scarce species present in the area in order to establish justified habitat preferences.

All species recorded by Theart et al. (unpublished) and by our sampling have been evaluated by the SARCA project except the Attenborough´s Flat Lizard (*Platysaurus attenboroughi),* that is because the project was carried out between 2005 and 2009, while this species was described later (Whiting et al. 2015). Of the 40 species evaluated, half were assessed at regional level, therefore the IUCN criteria were applied only for the countries covered by the project: South Africa, Lesotho and Swaziland. So populations from other countries, including Namibia, were not considered for the assessment. All species in the study area evaluated by SARCA project, both at regional and global levels, were listed as Least Concern (LC). On the other hand, only 10 of the 41 species recorded in the study area have been assessed directly by IUCN. This lack of assessment by IUCN can make significantly more difficult to understand the potential threats that these species may be facing globally, and the situation of cryptic species and subspecies that remain undetected to date may be particularly sensitive.

The case of the Tent Tortoise (*Psammobates tentorius)*, which was categorized by the SARCA project as a LC, is noteworthy. This species was evaluated by the IUCN in 2013 and the result of the evaluation was published in 2017 as Least Concern (LC). That same year the evaluation was repeated and since 2018 the Tent Tortoise is categorized by the IUCN as Near Threatened (NT). The species is widespread and still relatively common, but the populations are dispersed and scarce and are decreasing by approximately 10-20% on average over three generations (Hofmeyr et al. 2018). There are two subspecies *P. t. tentorius* and *P. t. verroxii* assessed at this time as Least Concern, but the third subspecies, *P. t. trimeni*, is assessed as Endangered (EN) under criterion A4ce (see Appendix 4). The subspecies present in our study area is *P. t. verroxii*, although recent genetic evaluations have shown that populations north and south of the Orange River differ from each other and state that *P. tentorius* consists of four deeply divergent lineages, with two lineages within *P. t. verroxii* (Hofmeyr et al. 2017). These findings could influence future assessments of the subspecies found in our study area by IUCN.

Future long-term studies in the same area are needed in order to be able to make well supported statements regarding the habitat preferences of each species and regarding the diversity of each habitat type.

6. Conclusions

KumKum and Pelgrimrust are areas of great diversity of reptile species despite the low abundance of individuals, with a relatively high abundance of very few species and a low abundance of most of them.

The lack of evaluation by the IUCN of the vast majority of species present in the area reflects the indifference with which this type of animal has traditionally been treated, despite the important work carried out at the regional level by SARCA project.

A priori, it seems that the habitat with the highest diversity is sandy plain, although the low number of individuals recorded for most species in the area reflects the need for a long-term study to be able to make well-founded claims about the habitat preference of the different species and about which habitat actually supports the highest reptile diversity. Long-term studies are especially necessary in mountain habitats, using sampling techniques focused on obtaining the best results in this type of habitat.

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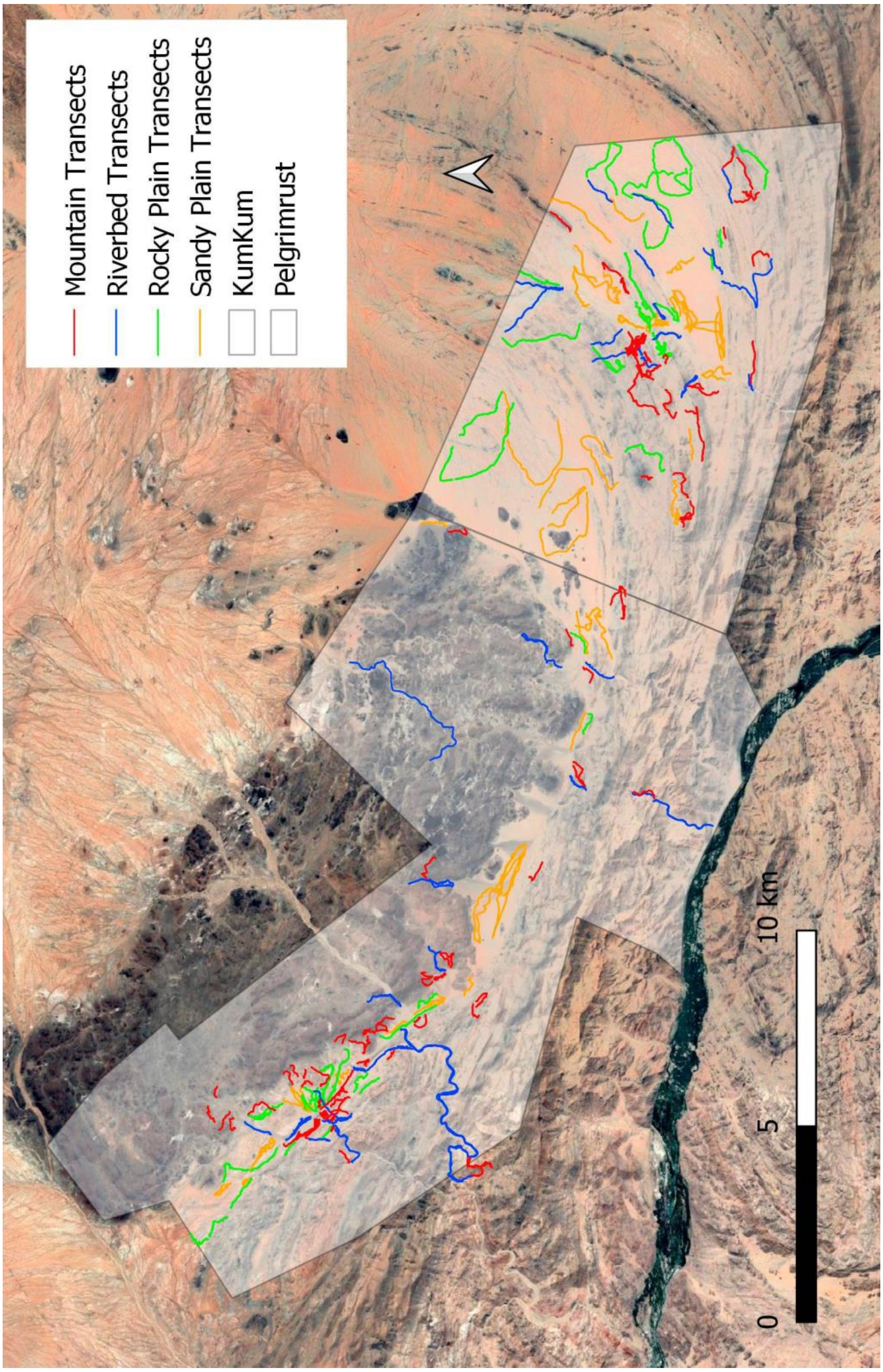
Appendices

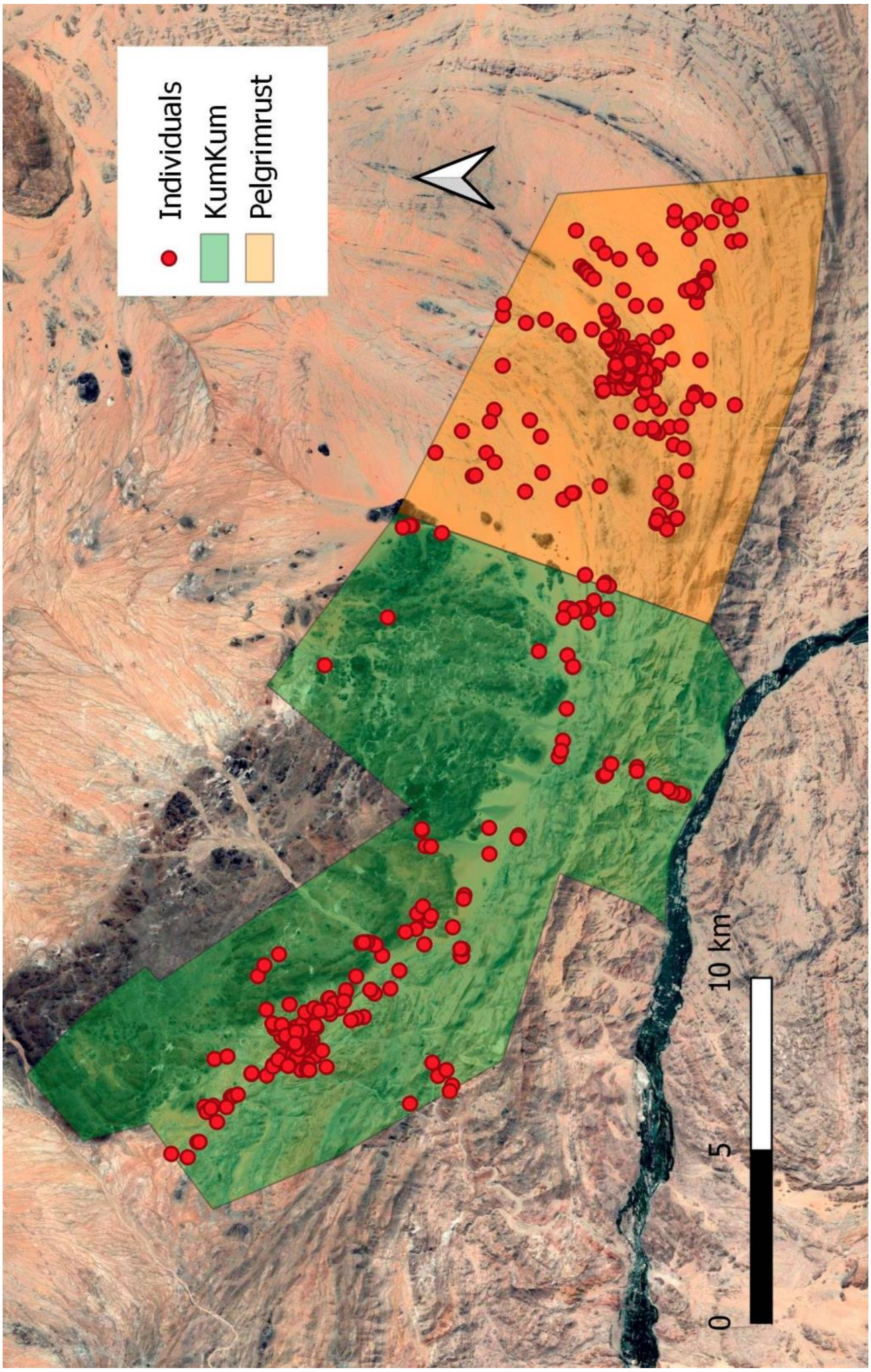
List of the Appendices:

Appendix 1: Distribution of the transects carried out in the different habitats of the study area



Map created using QGIS 3.8 Zanzibar Software.

Appendix 2: Distribution of the reptile individuals recorded in the study area



Map created using QGIS 3.8 Zanzibar Software.

Appendix 3: Photographic catalogue of the species recorded and habitat preferences attending to the literature consulted

Gekkonidae

Giant Ground Gecko (*Chondrodactylus angulifer*; left): occurs in the western part of South Africa, southern Namibia and southwestern Botswana. A large terrestrial gecko that burrows in compacted sand in sparsely vegetated sandy valleys.

Bibron´s Gecko (*Chondrodactylus bibronii*; right): occurs in southern Namibia, Botswana and South Africa. Inhabits rock outcrops throughout the Karoo region.

Bradfield´s Dwarf Gecko (*Lygodactylus bradfieldi*; left): occurs from South Africa through Namibia to southern Angola, isolated populations in Botswana and Zimbabwe. Arboreal, favours stands of *Acacia* trees along river courses.

Striped Dwarf Leaf-toed Gecko (Goggia lineata; right): restricted to South Africa and southern Namibia. Inhabit small rock outcrops and rock piles with low vegetation cover, and dead *Aloe* and *Crassula* stems.


Namaqua Mountain Gecko (*Pachydactylus montanus*; left): restricted from the Northern Cape, in South Africa, to southern Namibia. Found in rocky habitats from mountain slopes to cliff faces in arid and semi-arid regions.

Speckled Gecko (*Pachydactylus punctatus*; right): occurs in South Africa, Namibia, Botswana, Zimbabwe, Mozambique, Malawi, Zambia, Angola and the Democratic Republic of the Congo. Inhabit open habitats from grassy savanna to desert margins and dry riverbeds.


Common Rough Gecko (*Pachydactylus rugosus*; left): occurs in South Africa, Botswana, Angola and Namibia. Mainly associated with river courses and most often found under bark on dead trees or in association with dry, dead, fallen or standing trees. Also found under debris in areas of human activity.

Spotted Barking Gecko (*Ptenopus garrulus maculatus*; right): occurs in Namibia and South Africa. It is found mainly in dune habitats and sandy areas.

Agamidae

Western Ground Agama (*Agama aculeata*; top): occurs in Angola, Namibia, Botswana, Zimbabwe, Mozambique, Zambia, Swaziland and South Africa. Terrestrial lowland agama often found in dry sandy areas where it takes refuge under thorny bushes. Author: Daniel Hernández.

Southern Rock Agama (*Agama atra*; bottom left): occurs in South Africa, Namibia, Botswana and Swaziland. Rupicolous lizard found from rocky plains to mountain tops.

Anchieta´s Agama (*Agama anchietae*; bottom right): occurs in South Africa, Namibia, Angola, Botswana and Democratic Republic of the Congo.

Lacertidae

Spotted Desert Lizard (*Meroles suborbitalis*; top): occurs in South Africa, Namibia and Botswana. Inhabit open, sparsely-vegetated areas in desert and semi-desert.

Western Sandveld Lizard (*Nucras tessellata*; bottom left): occurs in South Africa, Namibia and Botswana. Associated with rocky terrain, but also frequents open karroid veld and dry riverbeds. Author: Handré Basson.

Spotted Sand Lizard (*Pedioplanis lineoocellata*; bottom right): occurs in South Africa, Namibia and Botswana. Prefer dry open plains with scattered vegetation.

Plain Sand Lizard (*Pedioplanis inornata*; left): occurs in South Africa and Namibia. Inhabits exposed bedrock on the lower slopes of mountains.

Namaqua Sand Lizard (*Pedioplanis namaquensis*; right): occurs in South Africa, Namibia and Botswana. Open sandy areas in karroid veld, arid savanna and semi desert.

Cordylidae

Attenborough´s Flat Lizard (*Platysaurus attenboroughi*): occurs in southern Namibia. As with other flat lizards this species is associated with rocky outcrops (predominantly granite in this region) and takes refuge in rock fissures. Author: Pieter Mier.

Gerrhosauridae

Dwarf Plated Lizard (*Cordylosaurus subtessellatus*): occurs in Angola, Namibia, South Africa and Botswana. Found among succulent and other karroid vegetation on small rocky outcrops in arid areas.

Scincidae

Namaqualand Dwarf Legless Skink (*Acontias tristis*; top left): occurs in South Africa and Namibia. Fossorial species found in sandy soils in arid to semi-arid habitats.

Western Rock Skink (*Trachylepis sulcata*; top right): occurs in Namibia and South Africa. Ripicolous species found on rocky outcrops in arid savanna, karroid veld and desert.

Western Three-striped Skink (*Trachylepis occidentalis*; bottom left): occurs in Namibia, South Africa, Angola and Botswana. Found in arid scrub and karroid veld.

Variegated Skink (*Trachylepis variegata*; bottom right): occurs in Namibia, Botswana, South Africa, Mozambique, Zambia and Zimbabwe. Found mainly in rocky areas but also in sandy gravel habitat.

Colubridae

Beetz´s Tiger Snake (*Telescopus beetzi*): occurs in Namibia and South Africa. Found in arid regions where it lives in rocky outcrops. It has also been collected from old termite mounds. Author: Johan Marais.

Elapidae

Cape Cobra (*Naja nivea*): occurs in Namibia, Botswana, South Africa and Lesotho. Inhabit arid karoo, open fynbos and grassland. Found in old mammals burrows and under rocks. It is a habitat generalist which adapts well to urban environments if sufficient remnant natural habitat is available. Author: Willem Van Zyl.

Lamprophiidae

South-western African Shovel-snout (*Prosymna frontalis*; juvenile top left; adult top right): occurs in South Africa, Namibia and Angola. Inhabit rocky areas in arid regions.

Western Whip Snake (*Psammophis trigrammus*; bottom left): occurs in Namibia, Angola and South Africa. It has been recorded from rocky patches on sandy soil near river valleys.

Karoo Whip Snake (*Psammophis notostictus*; bottom right): occurs in Namibia, Angola, South Africa and Botswana. Inhabit plain habitats as arid scrubland, karroid bushveld and fynbos habitats.

Viperidae

Horned Adder (*Bitis caudalis*; full body and portrait): occurs in Namibia, Angola, South Africa, Zimbabwe, Botswana and Zambia. Generalist, prefer hot, dry, open areas.

Desert Mountain Adder (*Bitis xeropaga*; full body and portrait): occurs in Namibia and South Africa. Found on sparsely-vegetated rocky desert slopes, generally associated with mountains.

Leptotyphlopidae

Western Worm Snake (*Namibiana occidentalis*): occurs in Namibia and South Africa. It is strictly subterranean in habits and restricted to arid environments.

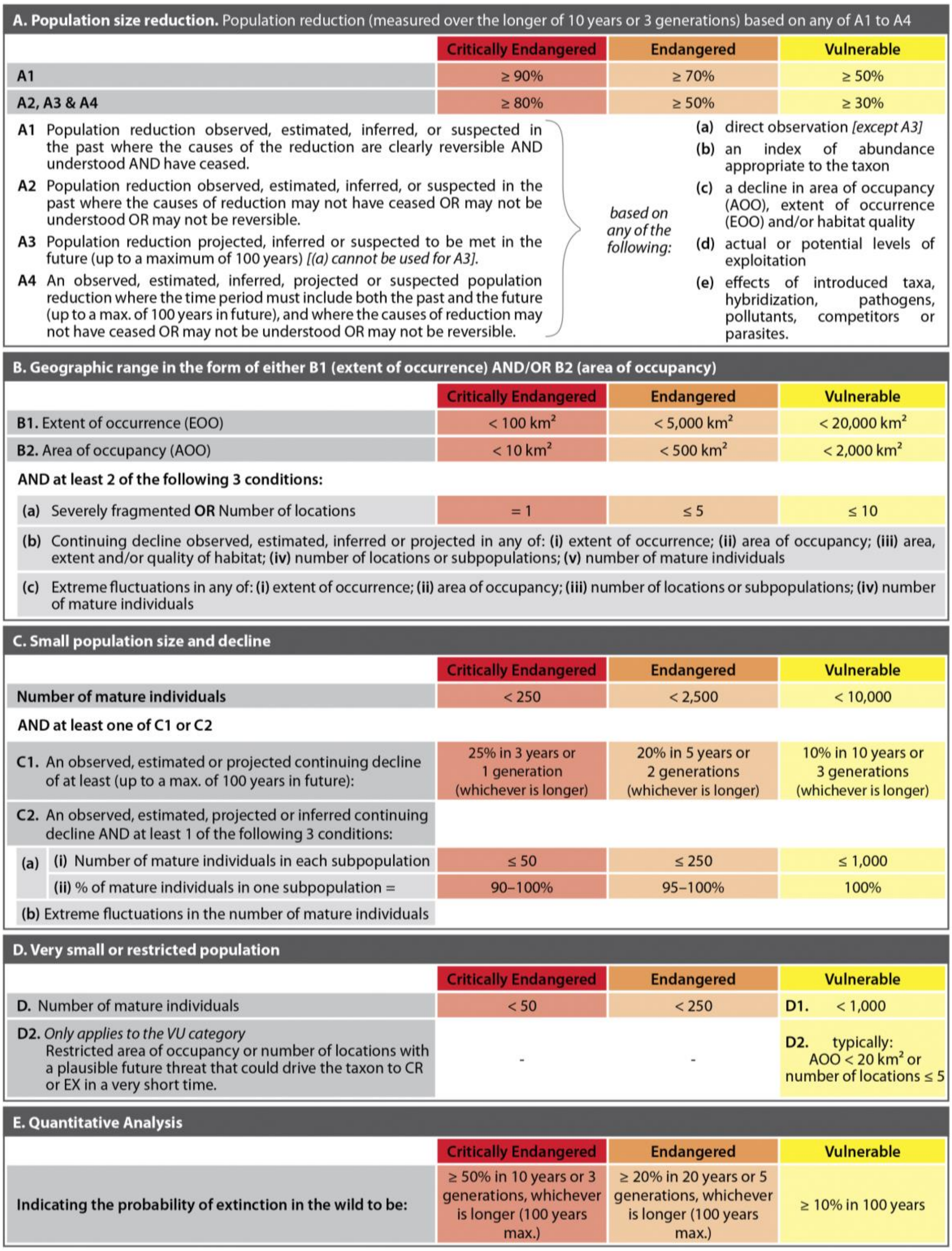
Typhlopidae

Delalande´s Beaked Blind Snake (*Rhinotyphlops lalandei*): occurs in South Africa, Namibia, Zimbabwe, Botswana and Mozambique. It is fossorial, using its hard beak to burrow into firm substrates.

Information provided in this Appendix has been consulted in IUCN (2020), Bates et al. (2014), Alexander and Marais (2007).

All photographs shown in this Appendix belong to the author of this study, except those in which a different authorship is explicitly indicated.

Appendix 4: Summary of the five criteria (A-E) used to evaluate if a taxon belongs in an IUCN Red List Threatened Category (CR, EN or VU)



A. Population size reduction. Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4

	Critically Endangered	Endangered	Vulnerable
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%

A1 Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased.

A2 Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

A3 Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years) *[(a) cannot be used for A3].*

A4 An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

based on any of the following:

- **(a)** direct observation *[except A3]*
- **(b)** an index of abundance appropriate to the taxon
- **(c)** a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality
- **(d)** actual or potential levels of exploitation
- **(e)** effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)

	Critically Endangered	Endangered	Vulnerable
B1. Extent of occurrence (EOO)	< 100 km^2	< 5,000 km^2	< 20,000 km^2
B2. Area of occupancy (AOO)	< 10 km^2	< 500 km^2	< 2,000 km^2
AND at least 2 of the following 3 conditions:			
(a) Severely fragmented **OR** Number of locations	= 1	≤ 5	≤ 10

(b) Continuing decline observed, estimated, inferred or projected in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** area, extent and/or quality of habitat; **(iv)** number of locations or subpopulations; **(v)** number of mature individuals

(c) Extreme fluctuations in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** number of locations or subpopulations; **(iv)** number of mature individuals

C. Small population size and decline

	Critically Endangered	Endangered	Vulnerable
Number of mature individuals	< 250	< 2,500	< 10,000
AND at least one of C1 or C2			
C1. An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future):	25% in 3 years or 1 generation (whichever is longer)	20% in 5 years or 2 generations (whichever is longer)	10% in 10 years or 3 generations (whichever is longer)
C2. An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions:			
(a) **(i)** Number of mature individuals in each subpopulation	≤ 50	≤ 250	≤ 1,000
(a) **(ii)** % of mature individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals			

D. Very small or restricted population

	Critically Endangered	Endangered	Vulnerable
D. Number of mature individuals	< 50	< 250	**D1.** < 1,000
D2. *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time.	-	-	**D2.** typically: AOO < 20 km^2 or number of locations ≤ 5

E. Quantitative Analysis

	Critically Endangered	Endangered	Vulnerable
Indicating the probability of extinction in the wild to be:	≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.)	≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.)	≥ 10% in 100 years

Source: www.iucnredlist.org