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Effectiveness of different sampling techniques for surveying herpetological communities in semi-desert environments in South Namibia

MASTER'S THESIS

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Author: Bc. Daniel Hernández Alonso

Chief supervisor: doc. Francisco Ceacero Herrador, Ph.D.

Declaration

I hereby declare that I have done this thesis entitled “Effectiveness of different sampling techniques for surveying herpetological communities in semi-desert environments in South 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 14th of May, 2020

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Daniel Hernández Alonso

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Czech University of Life Sciences Prague
Faculty of Tropical AgriSciences

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Abstract

Namibia is one of the countries in Africa where data on herpetofauna are scarce compared to other African countries and other areas of the world, with new species being described in recent years. Most of the reptile species listed in the country have not undergone any assessment by The IUCN Red List of Threatened Species. In order to make an evaluation, it is necessary to develop an effective methodology that allows gathering knowledge from herpetofauna present in arid environments, which are abundant in Namibia and African continent.

The main aim of this study was to improve the knowledge about the effectiveness of different methods used in herpetological studies in this kind of biomes, evaluating their efficacy. The study was carried out in the Nama-Karoo biome in southern Namibia between August and October 2019. The methods used were visual, stoning and fibroscope transects included in active methods, pitfall traps and coverboards arrays in passive methods and free search group encompassing all non-standardized methods. A list of 31 species of reptiles in the study area and 2 amphibians was compiled. The results showed that the most effective methods for detecting individuals and species were visual transects and free search methods in terms of capture rates for individuals and species. However, regarding the detection of certain groups, the need of using a complete set of methods was shown, being effective all the methods used, with the exception of fibroscope transects and coverboards, which were inefficient in this survey. The total sampling efficiency and comparison with other works indicate a necessity to continue surveying this area, estimating that there are still undetected species.

Further research on the comparison of methods over a longer period of time and in different seasonal periods is necessary to obtain a methodological set that allows the detection of individuals and species of different taxa in a complete way, increasing the necessary information on herpetofauna in regions with lack of data.

Key words: Nama-Karoo, rarefaction, herpetofauna, pitfall, efficacy.

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All the pictures except by those indicated, have own authorship.

List of the abbreviations used in the thesis

ACE: Abundance-based Coverage Estimator

Cb: Coverboards

CI: Confidence Interval

FS: Free search

FT: Fibroscope transects

NE: Not Evaluated

LC: Least Concern

LTRF: Labial Tooth Row Formula

PIR: Passive Infrared

PT: Pitfall traps

SBR: Sample-based Rarefaction

ST: Stoning transects

SVL: Snout-vent length

VST: Visual Sampling Transect

VT: Visual transects

1. Introduction and Literature Review

1.1. Introduction

Within this current trend of global biodiversity loss, two of the groups that suffer most from this tendency are amphibians and reptiles, with more than 23 % of species threatened and 17.3 % of species catalogued as Data Deficient (The IUCN Red List of Threatened Species 2020), excluding non-assessed species. This is not only a reflection of the current pronounced decline of these taxa, but also a lack of data on them, which is a major handicap in the conservation of species and populations of both groups.

They are sensitive to external factors such as habitat destruction and fragmentation, invasive species, pollutants, climate change and emerging diseases (Blaustein & Kiesecker 2002), which makes them excellent bio-indicators of the environmental health of ecosystems and thus the first to suffer the impact when they are altered.

However, they are also a group with a wide adaptive radiation to different environments, being successful even in deserts with interesting adaptations (Pianka 1986; Vitt & Caldwell 2014). Although in these areas the diversity of species is not as wide as in equatorial zones, it is remarkable and due to the harsh environment with such variable and limiting factors in which they live, the animals have some physiological, ecological and morphological adaptations that make them unique. Some of these are very short and marked patterns of activity, as well as their phenology, which makes them elusive and cryptic animals, which, in relation to the lack of data on the taxa, makes it difficult for researchers to study.

Nevertheless, deserts are ecosystems that are undergoing rapid alteration due to climate change (IPCC 2014), and amphibians and reptiles, being ectotherms, are believed to suffer particularly as they are more sensitive to temperature shifts (Vale et al. 2015; Griffis-Kyle et al. 2018). It is estimated that the process of modification is occurring too rapidly, and the evolutionary processes will not be able to generate an adaptive response that would allow these groups to survive (Etterson & Shaw 2001; Griffis-Kyle et al. 2018).

This situation of difficulty in sampling and the increase in factors directly affecting the decline of herpetofauna determines a need for the standardization of methods in these arid ecosystems to facilitate data collection in research.

Namibia is a country with scarce data regarding herpetofauna, reflecting a general situation in Africa except South Africa and Madagascar (Tolley et al. 2016). Few studies similar to that of Herrmann and Branch (2013) have been carried out in the country, but most have focused on a single species (Heideman 1995; 2002), which has also facilitated the discovery of new species recently (Broadley 1991; Dawood & Channing 2002; Branch 2007; Heinicke et al. 2011), opening up the possibility of the description of even more species not yet catalogued, favouring knowledge of species and populations and the urgency of developing conservation plans to protect them.

Since the scientific community has been aware of this problem for several years, an attempt has been made to evaluate the efficiency of sampling methods in search of standardization (Garden et al. 2007; Hutchens & DePerno 2009; McDiarmid et al. 2012), with conclusions that the efficiency of the different sampling methods varies, depending on the taxa and the geographical context, showing a great contrast in which a combination of methods is necessary to obtain a complete species list.

On a smaller scale, similar studies have been carried out testing the effectiveness of the techniques in different habitats. However, most have been produced in temperate climates and especially in tropical areas (Doan 2003; Rödel & Ernst 2004; Ribeiro-Júnior et al. 2008), as they are biodiversity hotspots for amphibians and reptiles. On the other hand, few studies have been carried out in arid areas (Molyneux et al. 2017; Richardson et al. 2017), so a greater effort is needed in these areas to cover the most elusive and cryptic herpetofauna abundant in the deserts, being crucial to obtain a methodology that allows the data gathering in the situation against the clock that we are currently experiencing. Thus, data collected during the present study will be shared with Atlasing in Namibia project, in order to improve the knowledge of herpetofauna in the country for researchers and citizens.

1.2. Literature review

1.2.1. Global situation and conservation status of herpetofauna

Today, biodiversity loss is an issue of great relevance and concern at the international level. For some years now, population and species declines have been studied by several researchers (Butchart et al. 2010; Ceballos et al. 2017), theorizing some authors with existing data on a future Sixth Mass Extinction in case taxa with "endangered" or "vulnerable" status continue to be lost (Barnosky et al. 2011).

In this widespread situation, one of the groups that are suffering most from population decline worldwide is amphibians. Since the early 1990s, some herpetologists began to raise this possibility (Blaustein & Wake 1990; Blaustein et al. 1994a), which was confirmed over the years with studies based on the compilation of data from different parts of the world (Houlahan et al. 2000; Stuart et al. 2004), and analysing the factors that promote negative population trends (Blaustein & Kiesecker 2002). Among the main threats causing the decline are habitat loss, degradation, and fragmentation (Cushman 2006; Becker et al. 2007), climate change, with several studies examining the influence of UV-B radiation (Blaustein et al. 1994b; 2003). Other main threats are pollutants (Sparling 2003), invasive species (Kats & Ferrer 2003) and diseases (Blaustein et al. 2012), most notably chytridiomycosis caused by the pathogen *Batrachochytrium dendrobatidis* Longcore, Pessier & D.K. Nichols (Skerrat et al. 2007; Fisher et al, 2009); all of them showing a marked anthropogenic influence.

This same idea was raised with a certain delay on the other group of ectothermic tetrapods, the reptiles, hypothesizing a higher incidence of decline on the latter due to the greater difficulty in describing population sizes accurately (Gibbons et al. 2000). Threats were also studied, sharing the same causes of global decline, adding unsustainable use to the list (Gibbons et al. 2000; Todd et al. 2010). As with the amphibian group, the efforts of some researchers have focused on assessing the conservation status of reptiles worldwide, indicating not only a decline in the group, but a lack of data at a global level, which is accentuated in tropical areas (Böhm et al. 2013). Smaller-scale studies have also been carried out underlining this lack of assessment of the conservation status of mainland African species in the IUCN Red List of Threatened Species project (Tolley et al. 2016), although subsequent work by Bates et al. (2014) shed light on this problem, but mainly in the South African region.

Because of this, there continues to be a lack of data for conservation of these taxa, both globally and at smaller scales such as in Africa. Due to this situation of data deficiency, a lot of species had been discovered recently (Broadley 1991; Dawood & Channing 2002; Branch 2007; Heinicke et al. 2011), with 335 reptile species described between 2010 and 2015 (Uetz et al. 2020), indicating the probability of extant species not yet catalogued due to the insufficient research.

1.2.2. Standardization of methods in herpetological studies

In order to overcome the lack of data and to achieve a correct estimation of the populations, numerous studies have been carried out in the last decades to standardize an effective methodology for these groups, usually grouped together in the term herpetofauna.

At first, these studies focused on the development of effective techniques, such as pitfall traps, funnel traps, etc.

Pitfall traps had been used in sampling certain vertebrates, combined with the design of drift fence arrays in the work of Gibbons and Semlistch (1981), which also analysed the advantages in terms of time investment related to the individuals captured. But also examined disadvantages such as high mortality rate due to drying out, predation or drowning in areas of abundant rainfall, or inefficiency for certain species such as anurans, some geckoes, large reptiles and also snakes that can escape from the buckets, confirmed by additional researches afterwards (Garden et al. 2007), being a specific method for certain taxa. This design, consists of a drift fence array acting as a barrier to facilitate the fall of animals into buckets, and was later used in numerous population studies of herpetofauna (Sung et al. 2011), suffering some modifications in particular cases (Hobbs et al. 1994; Enge 2001; McKnight 2013), in which the different designs of the drift fence arrays were evaluated, obtaining limitations of the design itself, whereas others studies (Spence-Bailey et al. 2010) focused on the external factors that can affect the trapping success of the method, as seasonality, temperature or moon phase.

Another technique is the active search transects, known as VST (Visual Sampling Transect) or simply Visual Transects, which are widely used in almost all herpetological studies; since it consists of the standardization of the classical search for individuals; and thus included in all kind of surveys and taxa. It is commonly used with amphibians (Rödel & Ernst 2004; Veith et al. 2004) and reptiles (Sewell et al. 2012) and they are non-specific, able to detect many species from different taxa. They can be standardized by time or distance. It has some variables that had been used for last years as road visual transects (Brown et al. 2012; Matos et al. 2012) due to the high mortality in such altered environments. Other variables are the use of vehicles at slow speed instead of walking transects, commonly used in the road transects.

As it occurred with Visual transects, the standardization of activities conducted along the time to find herpetofauna, is useful in achieving the best methods that can be used in scientific research. Other method used for long time that suffered this process is the activity of searching hidden animals beneath the rocks, logs and other environment features that serve as hideout for them, and they use for thermoregulation in a process called thigmothermy (Henderson et al. 2016), that consists of transferring the heat from the contact with the rock, while they are safe from predators. This method is commonly encompassed in quadrats, described and used in various studies (Corn & Bury 1990; Doan 2003; Meyers & Pike 2006), also including variations as excavating in the soil (Measey 2006) for fossorial species detection. Quadrats method consists of establishing plots that are sampled for some established amount of time in various occasions, thus require resampling and availability to visit these plots at the expected time.

Other methods such as coverboards and funnel traps were also described and used in several studies (Campbell & Christman 1982; Vogt & Hine 1982; Corn & Bury 1990), combined in many occasions with pitfall traps in the drift fence arrays design. Coverboards consists of providing artificial elements as shelter, useful for long-term studies (Ali et al. 2018) or amphibian surveys, for instance woodland salamanders (Willson & Gibbons 2006), as it is a specific method. Funnel traps are a technique that counters the deficit of pitfall traps in the capture of snakes and some anurans being specific for those groups, with a funnel design and an elongated container placed horizontally that allows the entry of snakes and other animals making their escape difficult.

From the 80s and 90s until now, efforts have focused on refining these techniques in terms of effectiveness and bias avoidance, and comparing them in different locations, mainly in tropical areas (Doan 2003; Rödel & Ernst 2004; Ribeiro-Júnior et al. 2008) as herpetological biodiversity hotspots, but few in arid areas (Molyneux et al. 2017; Richardson et al. 2017), concluding in more general reviews (Dodd 2010; Garden et al. 2007; Todd et al. 2007; Hutchens & DePerno 2009; McDiarmid et al. 2012; Ali et al. 2018), in a combination of methods to obtain a complete list of species due to the limitations and strengths of each method, and the difference in the effectiveness of these techniques very variable and dependent on the geographical factor and the species themselves, as amphibians and reptiles are groups of great evolutionary divergence that has led them to very different ways of life (arboreal, aquatic, fossorial, terrestrial...), with many combinations of methods as visual transects and pitfall traps (Garden et al. 2007), or glue traps, visual transects, pitfall traps and funnel traps (Ribeiro-Júnior et al. 2008). Some researchers emphasize the importance of taxa or groups when comparing the effectiveness of the methods and not only the number of species (Rödel & Ernst 2004), since some are really effective for few species that other methods are not.

In this period, apart from improvements in techniques, others also were developed such as the use of acoustic data loggers to record the presence of amphibians, which is another improvement of the method used for long time, the acoustic surveys. Acoustic surveys or call counting are widely used for surveying amphibians, being standardized in audio strips similar to transects, or without moving (De Solla et al. 2006), and lately modified with the inclusion of acoustic data logger devices that allow the record of the animal without human presence, collecting the data automatically, thus increasing their use in amphibian surveys (Meek 2010; Moreno-Gómez et al. 2019).

Other within these new methods was the use of fiber-optic borescope (Santoyo-Brito & Fox 2015; Parusnath et al. 2017), which is the use of video recording devices that have cable part with illumination system in the most distal part which can be introduced in crevices, holes, burrows and natural hideouts for the animals that cannot be sampled in other way, providing information about the fossorial, elusive and inactive individuals.

In addition, it was used another technique which is the use of PIR cameras (Molyneux et al. 2017; Richardson et al. 2017), commonly use in other taxa surveys as mammals. This method was used in combination with pitfall traps array for mammals and reptiles, placing PIR cameras to record the animals targeted.

With these recently developed methods, the process of animal stressing associated with other techniques that require contact with them is reduced or completely avoided, also providing accurate capture data as exact time or weather in case of PIR cameras. Another asset is the cost reduction in terms of time and effort for researchers in the field, since the data are collected automatically (both acoustic in the data loggers and visual in the cameras), improving previous techniques, but with the disadvantage of a higher economic cost, difficult to obtain in some studies.

1.2.3. Herpetofauna in the deserts

As for the previously mentioned ways of life, desert animals are especially elusive. Due to an adaptation to the climatic conditions of the arid zones, the ecology of these groups has been modified in such a way that convergences appear in the different deserts of the world (Pianka 1985; 1986; Vitt & Caldwell 2014), with marked patterns of activity and reproduction, and long periods of inactivity during the hottest hours and the months with the most adverse conditions, being even more marked in the case of amphibians due to their greater dependence on humidity because of their permeable skin, suffering a process of aestivation, minimising metabolic processes, along with other adaptations such as increasing the concentration of urea to avoid loss of water by osmotic gradient and even absorbing it from the substrate thanks to this, being possible for them to bury themselves for long periods of time (Wells 2007). These adaptations have allowed these groups of ectotherms to be successful in arid environments, especially for reptiles (Pianka 1986), which do not require such marked and limiting adaptations.

However, the deserts they inhabit are the fastest changing non-polar terrestrial ecosystems (IPCC 2014), and it is estimated that these tetrapod ectotherms that inhabit these types of habitats will suffer particularly from climate change (Vale et al. 2015; Griffis-Kyle et al. 2018), as these habitats contain numerous species with a narrow ecological niche, particularly amphibians (Griffis-Kyle 2016), making them even more vulnerable to shifts in climate factors (Slatyer et al. 2013). This affects reptiles at higher altitudes even more, as they are not adapted to such abrupt changes in temperature, since those in lower areas face daily lethal surface temperatures during the warmer months, having a wide repertoire of behaviours to cope with these very high temperatures (Barrows et al. 2010; Barrows 2011). Although evolutionary change may occur due to phenotypic changes caused by the plasticity and genetic variance of different populations, and adaptations to this climate change may occur (Urban et al. 2013), several authors believe that this process is occurring too quickly for evolutionary processes and natural selection to respond by generating adaptations that allow the survival of herpetofauna in these ecosystems (Etterson & Shaw 2001; Griffis-Kyle et al. 2018).

1.2.4. Desert and Karoo biomes

Africa is a continent with a large representation of arid regions. In the zone of the Southern Africa, these are distributed mainly in the western zone. The climatic conditions that favour this aridity are markedly influenced by the southern subtropical high pressure (anticyclone) belt, in the most southern areas by the circumpolar westerly airstream and in the western coastal area by the Benguela current (Desmet & Cowling 1999). Understanding the biome as a unit with similar vegetation structure and similar macroclimatic patterns (Rutherford et al. 2006), several biomes emerge in the south-western zone of Africa, due to the factors previously mentioned and adding other local factors such as mountain ridges and other geological formations, which cause great variability in terms of climatic factors, mainly rainfall, fog, dew, temperature, cloud, light and winds. As for these, the most significant when determining the different biomes is rain.

The Karoo is a biome with a greater range of rainfall than the Namib desert, with around 50 - 600 mm of annual rainfall. And within the Karoo, two biomes are distinguished with a very similar range of annual rainfall, but with another very important feature, which is the distribution of it, being the highest percentage of rainfall in winter in the Succulent Karoo, and a contrary seasonality in the Nama-Karoo, tending to summer (Mucina et al. 2006; Desmet & Cowling 1999), in addition to higher temperatures. This distribution causes vegetation to vary between these two biomes.

The climate of the Nama-Karoo is continental, with no oceanic influence. The average annual rainfall mentioned above suffers a gradient from the north where it limits with the desert biome towards the southeast where the greater rainfalls take place. The geographical features also produce a great variability in terms of temperature in this biome, with the highest temperatures in the area of the Orange River Valley, where the average temperature is around 21 ° C with highs exceeding 30 ° C in summer and lows of 6 ° C, with around 60 mm of average pluviosity (WorldWeatherOnline 2020). These higher temperatures correspond to the fact that in this area there is a gradient towards the desert biome that penetrates from the Atlantic coast following the course of the Orange River through the Bushmanland area, covering strips of 20 - 30 km from the riverbed. This biome is characterized by an average annual rainfall of less than 70 mm and a coverage of perennial vegetation of less than 10 %, without a definition by vegetation structure (Jürgens et al. 2006).

With respect to the soils and geology are also very different due to the extent of the biome. In the Orange River Valley area, metamorphic rocks such as gneiss, quartz and amphibolite predominate but also plutonic rocks, with the presence in the area of the Tantalite valley shear zone, of an extension of more than 500 km from the coast, crossing the Nama-Karoo of southern Namibia (Moore 1981).

As for the vegetation, it can be described as a biome with a 10 % total vegetation cover, abundance of herbaceous, dwarf shrub and deciduous trees, with many woody plants facultatively deciduous as adaptation to the rain seasonality (Okitsu 2010). It presents a lower species richness than other analogous biomes with a low rate of endemism. The dominant families are Asteraceae, Fabaceae and Poaceae, with relative prevalence mainly of Aizoaceae, Acanthaceae, Capparaceae and Cucurbitaceae in some areas. The seasonality of rainfall and the variability and low temperatures in winter do not allow the succulents to dominate as they do in Succulent-Karoo (Mucina et al. 2006). The desert biome bordering the Orange River is dominated by the families Acanthaceae, Poaceae, Capparaceae and Amaranthaceae (Jürgens et al. 2006).

Apart from the vegetation structure of the area, since 1900 several plant species have been introduced to this biome, the most successful and persistent in this area are mesquite trees (*Prosopis* spp. L.) in the lower areas or near rivers and prickly pear *Opuntia ficus-indica* (L.) Mill., being this Cactaceae species effectively dispersed by crows (Dean & Milton 2000). There is also presence of other species, but in a rather less conspicuous way.

1.2.5. Herpetofauna of Namibia

Namibia has a total of 45 species of amphibians encompassed in 11 families and with 4 endemisms (AmphibiaWeb 2020). Two hundred and seventy-six species of reptiles within 22 families had been recognized (Uetz et al. 2020), whereas Griffin (2003) reported 228 species with 21.2 % endemics. This means a high biodiversity and species discovery, which is focused in some points, mostly the centre and the wetter areas in the north and northeast of the country. However, there are also areas with high biodiversity such as some parts of the coast, the southern part of the country, whose border with South Africa is the Orange river, or the Namib desert, which also has a high degree of endemicity (Herrmann & Branch 2013).

2. Aims of the Thesis

This thesis is part from a larger project encompassed in Southern Namibia in order to get information about the distribution and populations of herpetofauna. As it is a long-term project, it is important to know the effectiveness of the different sampling methods in the Nama-Karoo biome to reach the most effective methodology set to gather data, being the evaluation of the effectiveness of the methods, the main aim of the thesis. With this purpose and as a first approach in the area, the thesis had the following aims:

1) Estimation of general efficacy of sampling methods regarding species and individuals capture rate.
2) Estimation the efficacy among the different taxa.
3) Identifying the best methodology set for sampling herpetofauna in the Nama-Karoo biome.
4) Evaluation of sampling effort necessary.
5) Actualization of the species list in the area.

We expected that the methods would not be equally effective, some of them being non-specific and detecting many individuals and species as Visual Transects, and others more specific but useful in detecting certain species and taxa as Fibroscope Transects or Pitfall Traps.

3. Methods

3.1. Study area

The study area is located in the south of Namibia, on the border with South Africa established by the Orange River, in the Karas region. The biome in which is located is mainly Nama-Karoo, but due to its proximity to the Orange River there is a gradient towards a desert biome in the areas closer to the river course. Data recorded in the Tantalite Valley near the study area show a range of minimum and maximum monthly temperatures between 6° and 35°, and a Mean Annual Rainfall of 45.8 mm in the last 10 years (WorldWeatherOnline 2020). The study area is represented in Figure 1.

It encompasses two different territories that in the past were used as Game Ranch, and after the cessation of this activity, a land management project was initiated with the intention of holding conservation plans, including another two land properties called Pelladrift and Kambreek, but none of the research was carried out in those territories. The research was carried out in the territories of KumKum and Pelgrimrust, with an extension of 187 km^2 and 105 km^2 respectively, and an approximate altitude range of 600 - 900 m, with higher mountain peaks up to 1050 m approximately.

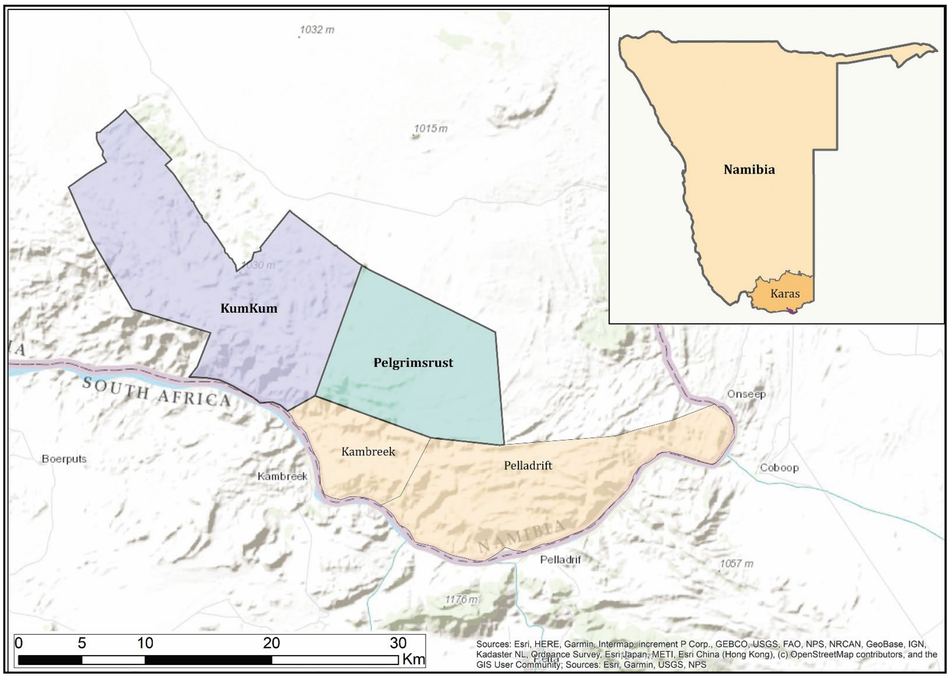


Figure 1. Map representation of the study area.

In this an arid zone, there are some well-differentiated microhabitats, with vegetation representative of Nama-Karoo biome in some areas and more similar to the vegetation units of the desert biome in others. There is a huge gabbroidal formation in KumKum area forming a large mountain massif, while Pelgrimrust is more defined by plains and metamorphic mountain ridges. General habitat image is shown on Figure 2.

Figure 2. Image of the study area in KumKum territory. The mountains at the back part of the picture belong to KumKum gabbroidal massif.

3.1.1. Sandy plain

It is a micro-habitat with scarce vegetation, with a sandy and uniform substrate in wide extensions without changes in altitude (Figure 3). The predominant vegetation are sub-shrubs and annual plants, conspicuous in spring. There is also presence of shrubs, mainly *Asparagus capensis* L., *Euphorbia dregeana* E.Mey., *Euphorbia gregaria* Marloth, and *Sysindite spartea* E.Mey. ex Sond., as well as plants present in both shrub and tree forms such as *Boscia foetida* Schinz, *B. albitrunca* Gilg & Gilg-Ben. or *Commiphora capensis* Engl, and isolated deciduous trees of the genus *Acacia* Mill., succulent trees of *Aloidendron dichotomum* (Masson) Klopper & Gideon F.Sm., used by the sociable weaver (*Philetairus socius* (Latham, 1790)) for the construction of their nests, which are also used by several species of reptiles.

There is also isolated presence of other plants such as *Codon royenii* L., *Hoodia gordonii* Sweet, *Acanthopsis disperma* Harv. or *Barleria lichtensteiniana* Nees among others.

In the uniform substrate there are few rocks or stones, but it is used by fossorial animals to build their burrows, from small holes of small mammals and reptiles to the large holes created by the aardvark (*Orycteropus afer* (Pallas, 1766)), which serve as a refuge for various animals including reptiles.

Figure 3. Sandy plain habitat with typical low vegetation cover.

3.1.2. Rocky plain

This is a microhabitat with greater altitudinal variation, but without steep slopes. In this the soil is firm and consists mostly of small to medium sized rocks, generally quartz and amphibolite, with larger rocks of the same type (Figure 4).

In this kind of plain occurs the largest presence of vegetation during winter, although the vegetation cover varies within the study area depending on the geographical location. Shrubs predominate in this microhabitat, with a greater representation of milk bushes (*Euphorbia dregeana* and *E. gregaria*) and some sub-shrubs, in addition to isolated specimens the same species of trees found in the sandy plains, but not *Acacia* sp.

Figure 4. Rocky plain. Greater vegetation cover represented predominantly by shrubs of *Euphorbia* spp. is characteristic of this habitat.

3.1.3. Riverbed

In the area, there are numerous dry riverbeds that cross other microhabitats, but these have different characteristics, with less compact soil, and variable presence of rocks.

Figure 5. Dry riverbed. Loose soil, different vegetation and variations between rocks and sand are typical features of this habitat.

The vegetation of these is quite different (Figure 5) from that of the plains, with a predominance of abundant species of shrubs such as *Cadaba aphyla* (Thunb.) Wild, *Sarcostemma viminale* (L.) R.Br., *Tamarix usneoides* E.Mey. or *Parkinsonia africana* Sond., and trees generally of the genus *Acacia*, more abundant than in the plains, and with a reduced presence of chamaephytes and therophytes.

3.1.4. Mountain

This microhabitat has the common characteristic of higher altitude than the others, with pronounced slopes. The geology is variable given the complexity and diversity of the area in this aspect, and amphibolites, plutonic rocks, granite gneiss, gabbroidal rocks may predominate depending on the area. In KumKum there is a gabbroidal formation at the north of the area, while the south and Pelgrimrust have mountains mainly formed by metamorphic processes. The substrate is usually composed mainly of large rocks, but with abundance of medium sized rocks. Regarding vegetation, it is a poor microhabitat with little presence of any vegetation, being the predominant species *Ailodendron dichotomum* (Figure 6), and scarce presence of some Euphorbiaceae like *Euphorbia dregeana* and *E. virosa* Willd. or some Crassulaceae and chamaephytes isolated.

Figure 6. Mountain habitat with *A. dichotomum*, in Pelgrimrust.

The Orange River is not a micro-habitat per se, but its conditions so different from the rest of the micro-habitat make it necessary to separate it. In the part of the study area where it is possible to access the riparian zone, there are sandy parts such as the sandy plains, mountain areas and rocky areas which are different from the rocky plains, because the geology of this zone is strongly affected by the erosive processes of the water, and there are rocks of all sizes. General picture is shown on Figure 7.

However, the most notable difference is in the presence of the river, which provides a shift in vegetation and fauna. In this area it is the only one with abundant vegetation, where perennial grasses are present all year, as well as being the only site where there are reeds, but the predominant species is an South American invasive plant, the mesquite trees (*Prosopis* spp.), which completely dominate the landscape. This habitat is altered by anthropic factors (Figure 8), with presence of domestic cattle and fires deliberately started by humans, in order to drive the leopards away from the cattle herds.

Figure 7. Pond in the Orange river basin. This kind of water bodies are a suitable habitat for amphibians.

Figure 8. Anthropic alterations in the Orange river. a) Fire started by humans. b) Cattle in Orange river basin.

This green area is also the ideal habitat for some amphibian species, as well as for other animal species found only in this part of the study area, being rich in the ornithological aspect with species such as pied kingfisher (*Ceryle rudis* (Linnaeus, 1758)), malachite kingfisher (*Corythornis cristatus* (Pallas, 1764)), giant kingfisher (*Megaceryle maxima* (Pallas, 1769)), hadada ibis (*Bostrychia hagedash* (Latham, 1790)), African sacred ibis (*Threskiornis aethiopicus* (Latham, 1790)), African fish eagle (*Haliaeetus vocifer* (Daudin, 1800)), swallow-tailed bee-eater (*Merops hirundineus* Lichtenstein, AAH, 1793), goliath heron (*Ardea goliath* Cretzschmar, 1829), black stork (*Ciconia nigra* (Linnaeus, 1758)), African darter (*Anhinga rufa* (Daudin, 1802)), South African shelduck (*Tadorna cana* (Gmelin, JF, 1789)), spur-winged goose (*Plectropterus gambensis* (Linnaeus, 1766)) and Egyptian goose (*Alopochen aegyptiaca* (Linnaeus, 1766)) among others. And the same occurs with the mammals, with the presence of chacma baboon (*Papio ursinus* (Kerr, 1792)), African clawless otter (*Aonyx capensis* (Schinz, 1821)) and vervet monkey (*Chlorocebus pygerythrus* (F. Cuvier, 1821)), which are only found in this area.

3.1.5. General fauna

Apart from the soil characteristics and the vegetational composition of the microhabitats, the fauna that inhabits the area is also relevant, since one factor of the ecosystems are the interspecific interactions, there being predators and prey of the taxa on which the study is focused, in addition to other interactions that occur in a less direct way.

A total of 82 bird species were recorded in the study area during the research period, with an abundance of passerines such as the African red-eyed bulbul (*Pycnonotus nigricans* (Vieillot, 1818)), rock martin (*Ptyonoprogne fuligula* (Lichtenstein, 1842)), pale-winged starling (*Onychognathus nabouroup* (Daudin, 1800)), mountain wheatear (*Myrmecocichla monticola* (Vieillot, 1818)), Karoo scrub robin (*Cercotrichas coryphaeus* (Vieillot, 1817)), Cape sparrow (*Passer melanurus* (Statius Müller, 1776)), sociable weaver (*Philetairus socius* (Latham, 1790)), southern masked weaver (*Ploceus velatus* Vieillot, 1819), Cape bunting (*Emberiza capensis* Linnaeus, 1766), bokmakierie (*Telophorus zeylonus* (Linnaeus, 1766)) and various lark species as Karoo long-beaked lark (*Certhilauda subcoronata* Smith, 1843) and Stark's lark (*Spizocorys starki* (Shelley, 1902)) that were identified.

There were abundant other species as laughing dove (*Streptopelia senegalensis* (Linnaeus, 1766)), Cape turtle dove (*Streptopelia semitorquata* (Rüppell, 1837)) and Namaqua sandgrouse (*Pterocles namaqua* (Gmelin, 1789)). The presence of raptorial birds was conspicuous, with Pale chanting goshawk (*Melierax canorus* (Thunberg, 1799)), Verreaux's eagle (*Aquila verreauxii* Lesson, 1830), booted eagle (*Hieraaetus pennatus* (Gmelin, 1788)), yellow-billed kite (*Milvus aegyptius* Gmelin, 1788), lappet-faced vulture (*Torgos tracheliotos* (Forster, 1791)) present in the area, as spotted eagle-owl (*Bubo africanus* Temminck, 1821), pied crow (*Corvus albus* Statius Muller, 1776) and other birds that can prey on reptiles.

Regarding mammals, 38 species were detected during the fieldwork by direct, sign and camera traps used in other researches. There are ungulates conspicuous in the habitat, being the most abundant mountain zebra (*Equus zebra* Linnaeus, 1758), common eland (*Taurotragus oryx* (Pallas, 1766)), greater kudu (*Tragelaphus strepsiceros* (Pallas, 1766)), springbok (*Antidorcas marsupialis* (Zimmermann, 1780)) and klipspringer (*Oreotragus oreotragus* (Zimmermann, 1783)).

The area is inhabited also by leopard (*Panthera pardus* (Linnaeus, 1758)) and small carnivores as honey badger (*Mellivora capensis* (Schreber, 1776)), striped polecat (*Ictonyx striatus* (Perry, 1810)), black-backed jackal (*Canis mesomelas* Schreber, 1775) or genet (*Genetta genetta* (Linnaeus, 1758)). Other small mammals are present as Cape ground squirrel (*Xerus inauris* (Zimmerman, 1780)), Cape hare (*Lepus capensis* Linnaeus, 1758), rock hyrax (*Procavia capensis* (Pallas, 1766)), South African springhare

(*Pedetes capensis* (Forster, 1778)), Western rock sengi (*Elephantulus rupestris* (A. Smith, 1831)), Cape short-eared gerbil (*Desmodillus auricularis* (Smith, 1834)) or Egyptian slit-faced bat (*Nycteris thebaica* E. Geoffroy Saint-Hilaire, 1818) among others.

Lastly, a total of 38 invertebrate species were identified in the area during the survey period, but of course this is a small number compared on the real amount of this group that is present in the area due to the lack of expertise and difficulty for identifying most of the groups. This particular group is especially interesting for the reptiles as possible preys, with presence in the area of termites as *Hodotermes mossambicus* (Hagen 1858) and species from Nasutitermitinae subfamily, 9 Odonata species as common hooktail (*Paragomphus genei* (Selys, 1841)), red-veined dropwing (*Trithemis arteriosa* (Burmeister, 1839)), *Phyllomacromia picta* (Hagen in Selys, 1871) or *Anax imperator* Leach, 1815, 7 scorpion species as *Parabuthus granulatus* (Hemprich & Ehrenberg, 1828) or *Opistophthalmus gigas* (Purcell, 1898). Moreover, numerous species of Orthoptera, Coleoptera and Neuroptera among others put together a large and wide group of invertebrates that interact with reptiles as preys or predators.

3.2. Previous studies and expected species

A previous study was carried out in the area in 2018 by Theart et al. (unpublished) with a total of 31 registered species. In addition, there are also confirmed records of 4 other species, one within the study area and the remaining in the vicinity. In addition to this, the species expected by Theart et al. (unpublished), and according to the distribution reported in Alexander and Marais (2013) and Bates et al. (2014), 20 more species of reptiles could be expected, all included in a total of 15 families, making a total of 56 possible species that could occur in the zone.

For amphibians, the expected species are based on the distribution maps in the work of Du Preez and Carruthers (2017), and AmphibiaWeb (AmphibiaWeb 2020) as there are no previous studies on this subject in the area, with a total of 14 possible species.

3.3. Data collection

Data collection was carried out from beginning of August to the end of October, during winter and early spring season in the southern hemisphere, matching the start of herpetofaunal activity.

The methods used for the data collection were divided into three groups: active methods, passive methods, and free search - other methods (non-standardized). In all of them, pictures were taken from individuals with complicated identification when possible. The sampling days were carried out with the same total daily effort adding up all the methods, involving more Free Search on days with less effort from other methods.

The fieldwork period encompassed 71 working days. A total amount of 312 transects were performed during the data collection, encompassing 198 Visual Transects, 77 Stoning Transects and 37 Fibroscope Transects. Regarding the passive methods, they were set up and active for 44 days, checked twice per day reaching 88 checking events or half days. Free Search methods were applied for 66 days, covering most of the daytime periods.

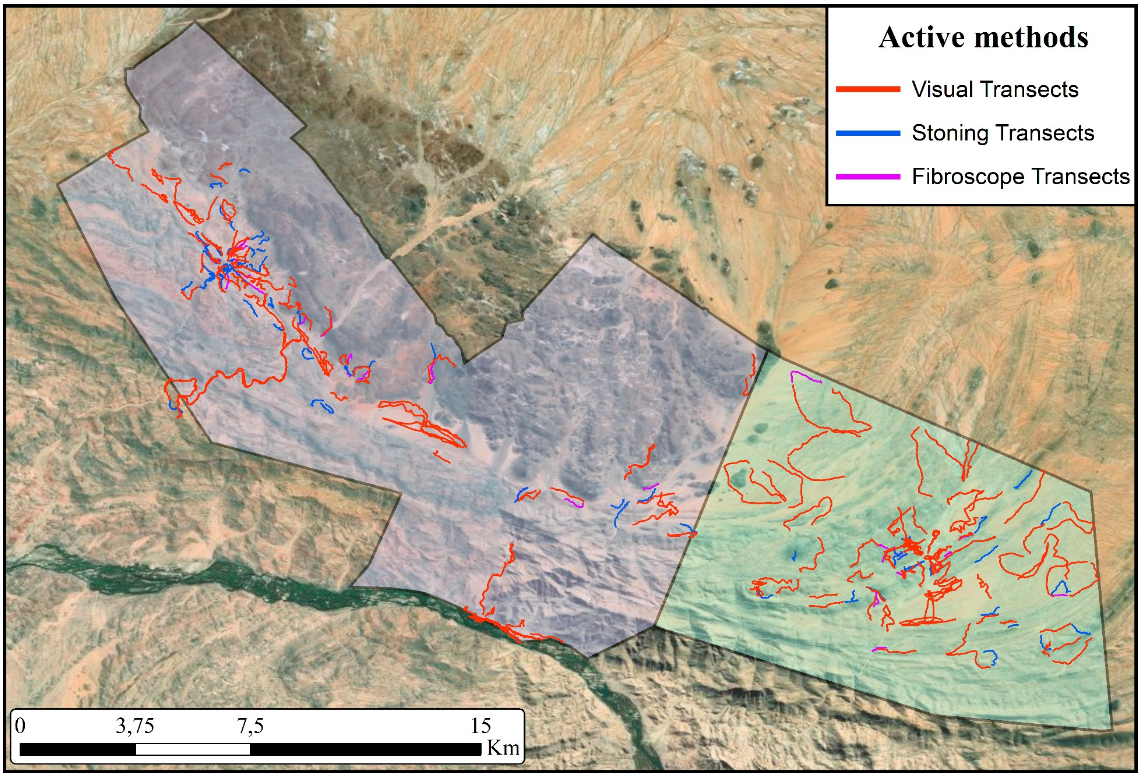


Figure 9. Representation of the transects in the survey.

With the data recorded by the Geo Tracker 4.0.2 software during the fieldwork, the transects made from the different methods during the study were represented with ArcMap 10.5.0 (ESRI, CA, USA) software. Transects done during the fieldwork are represented in Figure 9.

The reptile individuals detected were identified based on field guides (Marais 2011; Channing et al. 2012; Alexander & Marais 2013; Bates et al. 2014; Du Preez & Carruthers 2017) and identification sheets with information from them.

3.3.1. Active methods

It encompasses three kind of active transects, in which researchers make a human effort to find individuals. The methods chosen were Visual Transects, Stoning Transects, widely used in herpetological studies and of proven effectiveness (Hutchens & DePerno 2009; McDiarmid et al. 2012; Ali et al. 2018), also indicated for arid environments (Molyneux et al. 2017). In addition, transects with fiber-optic borescope were added, more recently introduced but useful for elusive species (Parusnath et al. 2017). These transects were standardized by time, being one hour transects, at a constant speed and performed in only one microhabitat per transect. For this type of methods, the use of a vehicle was essential in order to cover a larger extension of the vast study area. All the transects were recorded with the Geo Tracker 4.0.2.1750 software, including also all the points of the individuals' observations. Transects were done during the morning and midday for detecting the diurnal species and at sunset and first night hours in order to detect crepuscular and nocturnal species.

The following information was recorded for each transect:

- Kind of transect
- Date
- Start and end time
- Track ID
- Microhabitat
- Weather (cloudiness, wind)

- Percentage average of substrate type along the transect, divided into groups:
    - Sand
    - Small stones (< 5 cm)
    - Medium sized stones (5-50 cm)
    - Big rocks (> 50 cm)
- Percentage average of vegetation type along the transect, divided into groups:
    - Grass
    - Sub-shrub
    - Shrub
    - Tree

The following information was recorded for each observation:

- Species
- Substrate were individuals was first observed
- Percentage average of the substrate type within a 5-meter radius with the same division as in the transects
- Percentage average of the vegetation type within a 5-meter radius with the same division as in the transects
- Number of individuals and their category in case it is possible to be determined:
    - Male/ Female
    - Adult/ Juvenile
- Individual activity:
    - Active/ Inactive/ Dead
- Picture reference in case of being photographed

In one same observation, more than 1 individuals may be recorded when they are near each other (< 5 m).

3.3.1.1. Visual Transect

Consists of doing the transect considering only direct visual observations. For this type of transect, the device with the Geo Tracker software, a herpetological hook, cloth bags to keep the individuals in case they were captured, and a field notebook to record the transects and individuals were carried as necessary equipment.

3.3.1.2. Stoning Transect

In this method the time of the transect is spent flipping stones, rocks, and logs along the microhabitat in order to find hidden individuals that are inactive. Because of this, it is difficult to do it in microhabitats where there are hardly any rocks, as sandy plains. For this type of transect, it was necessary, in addition to the materials mentioned for Visual Transects, some herpetological safety gloves to protect the hands when lifting the rocks and from a possible quick bite from some venomous snake at the moment of lifting the rock.

3.3.1.3. Fibroscope Transect (Fiber-optic borescope)

This type of transect consists of searching for reptiles and amphibians that may be hidden among rocks, holes, cracks, crevices... by the use of an electronic device, the fiber-optic borescope that allows recording and illuminating the aforementioned holes through the cable, showing the images on the screen. For this type of transect only the field notebook, the mobile phone and the fibroscope itself were necessary.

3.3.2. Passive methods

It includes methods in which the capture of the animals does not require direct presence. These are standardized to the number of times checked or half days, as they were checked once in the morning and once in the afternoon to reduce the high mortality rate associated with some of these methods.

3.3.2.1. Pitfall Traps

Three pitfall traps with drift fence arrays, henceforth called Pitfall Traps, were designed, and constructed according to the design of Figure 10, used in herpetological studies in arid zones (Hobbs et al. 1994; Thompson & Thompson 2007; Theart et al. unpublished). The traps were built with canvas, wire, plastic buckets, and wooden stakes, with dimensions of 20 m long and 30 cm high with 5 cm buried in the sand to prevent the passage of animals by digging. Another C-shaped structure with 80 cm of each wing was made at both ends, following Theart et al. (unpublished) design, to facilitate capture. A piece of sponge and a stone was introduced into each bucket to reduce the mortality rate, with the sponge being moistened at every check.

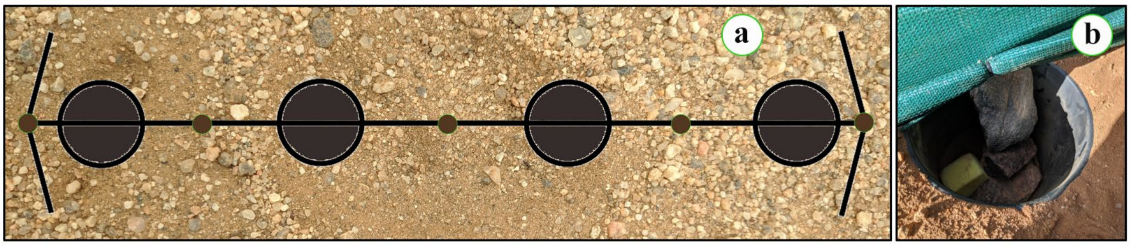


Figure 10. Pitfall Trap design. a) Pitfall Trap drift fence array design used in present study. b) Bucket of closed trap, with small sponge and stones that allow the exit.

Information was collected from the traps indicating the presence or absence of reptiles in each bucket, and if so, the species, whether the capture bucket was inner or outer, and the picture reference if photographed. When closed, a big stone that allowed the escape was placed (Figure 10b). Complete set up is shown on Figure 11.

Figure 11. Pitfall trap set up in the study area.

3.3.2.2. Coverboards

Coverboards were also used, widely applied in herpetological studies (Rice et al. 1994; Hutchens & DePerno 2009; Ali et al. 2018). The coverboards were designed in two sizes 160 × 90 cm and 90 × 80 cm using white plywood sheets, and located within 10 m radius from pitfall traps, two large and two small per trap. These were also checked twice a day as were the Pitfall Traps.

3.3.3. Other methods – Free Search

This group includes non-standardized methods or methods with additional data to others, such as car transects, active search of individuals outside transects, casual encounters in the anthropic environment and individuals detected by a method different from the one used in the transect. Individuals were recorded in the same way as in the transects, without adding the data of substrate and vegetation when individuals were found in the anthropic environment. Due to the various data, it was impossible to standardize the daily effort for these methods together.

Acoustic detection was also performed using AudioMoth devices, data loggers that were placed to detect and record amphibians in the Orange River area, but due to technical problems of devices being stolen and destroyed by chacma baboons (*P. ursinus*), in addition to the different species target in comparison with the rest of the methodology, they will not be analysed in this work.

3.4. Data analysis

For the analysis of the data, matrices were made in Microsoft Excel 2016 with the number of samples and the individuals found in each sample unit, thus representing the abundance data obtained during the fieldwork. A matrix of sampling units and species/individuals was made for each method, as well as one total.

3.4.1. Species accumulation curves, asymptotic species richness estimators and rarefaction curves

These matrices were analysed in EstimateS 9.1.0 (Colwell 2013) software, loading as sample-based incidence or abundance data and calculating the diversity with 100 runs of randomisation without replacement. Under the conditions of the study with an abundance-based dataset, a non-parametric species richness estimation was performed, since the most common species provide hardly any information about undetected species, while rare or infrequent species contain almost all the information about those undetected species (Chao & Chiu 2016). Thus, the most reliable were Chao1 and ACE (Abundance-based Coverage Estimator), accurate asymptotic estimators when the asymptote is reached on the species accumulation curve, and which are based on singletons (species recorded once) and doubletons (species recorded twice). Therefore, they were used to estimate species richness and thus to compare the effectiveness of the sampling.

- **Chao1**: This estimator is based on rare species and works satisfactorily when undetected species are as likely to be detected as a singleton (Chao & Chiu 2016).
- **ACE** (Abundance-based Coverage Estimator): It is based on the sample coverage, the proportion of the richness of the set represented by the species in a sample (Gotelli & Colwell 2011). However, this estimator is undefined for cases where all rare individuals are singletons, and in such a case it is recommended to use the Chao1 estimator (Colwell 2013).

With the real data of the sampling period and the estimators, a series of species accumulation curves were made. The species accumulation curves describe the total number of species revealed during the data collection, as more sample units or individuals are added up to the pool of previous individuals detected or samples, thus representing the effort accumulated for detecting the species represented by the sampling units. These curves increase until the asymptote is reached, at which time theoretically all species have been detected. This curve increases rapidly when abundance is distributed evenly, and conversely, will increase slowly when there are few common and many rare species, with most individuals of common species being added to the curve from species that have already been sampled. Comparing these is complicated, as it may reflect differences such as uneven sampling effort or conditions, usually giving the comparison to misleading results (Gotelli & Colwell 2001; 2011).

Comparing the number of detected species with the richness estimated by Chao1 and ACE, taking these data as a hypothetical real richness, we obtain a sampling efficiency by dividing the number of observed species by the estimated one, and multiplying it by 100 to obtain a percentage value.

Another curve was made for the standardized transect methods, similar to the species accumulation curve mentioned above, but considering distance units (km) as sampling units instead of transects. This data is only available for the active methods standardized by transects, thus this analysis was only done for those methods. In this curve, like in the previous species accumulation curve, it was considered the first detection of each species, obtaining a result of distance in terms of effort until the encounter of that species.

Rarefaction curves were also made, different from the previous accumulation curves, since they represent the means of the repeated re-sampling of the individuals in the pool, thus representing the statistical expectation for the respective accumulation curves (Gotelli & Colwell 2011). However, they do not represent a true species richness from the dataset but estimate it for a sub-sample from the pooled total species richness, based on the empirical reference sample.

With abundance data from the fieldwork, sample-based rarefaction (henceforth SBR) curves were calculated. They must be based on at least 20 samples, and allow the comparison of two sample sets when they have similar taxa and a comparable sampling effort, by rescaling the x-axis from number of samples to individual abundance (accumulated number of individuals) when sample sizes are close. This reduces the bias when both methods have similar amount of sample units, and although they do not provide a direct comparability of different methods, they do allow the comparison of the efficiency of different sampling methods in the same area (Ellison et al. 2007; Gotelli & Colwell 2001; 2011). EstimateS 9.1.0 (Colwell 2013) computes a SBR curve and also Coleman rarefaction curve for sample-based abundance data, a modification of the individual-based rarefaction, applied to this kind of dataset (Colwell 2013), being more reliable the SBR (Colwell, pers. comm.), therefore SBR curve was chosen for the analysis.

3.4.2. Species detected, individuals detected and capture rate

In order to evaluate the effectiveness of the methods, the species caught by each one and the capture rate were measured by direct calculation from the data obtained during the fieldwork.

It was also done by dividing individuals and species into groups or taxa, to evaluate which methods were more effective in capturing or detecting those groups, and conversely, to determine for which taxa were ineffective. In this case, the groups are Lizards, which include the families Agamidae, Lacertidae, Scincidae, Cordylidae and Gerrhosauridae; Geckoes in which only the family Gekkonidae is represented; Snakes which include Viperidae, Lamprophiidae and Elapidae; and finally Blind Snakes which include the families Leptotyphlopidae and Typhlopidae.

In this way, it is possible to evaluate if a method is effective in terms of individuals recorded, or if it is not, but instead recording an elevated number of species, among other possible combinations.

3.4.3. Species - specific methods

Within the species detected in a sampling, it is important to know which groups or taxa are detected by each method. Not only this information is relevant, but on a more specific level, which species are detected by the methods, because within the groups, there are species with very different habits, lifestyles, and behaviours. For this reason, a matrix of shared species between methods was made, showing the percentage and number of species shared between the different methods.

In addition, species detected by only one or two methods were also calculated, representing the methods and the number of the species with this requirement that they detect. In this way, is possible to know which methods are effective detecting species for which other methods are not, independently of how common or rare are they.

3.4.4. Rank/abundance plot

Apart from the detection of individuals or species and the capture rate, it is relevant to know which species are the most common for our methods. There may be species represented by a large number of individuals and others by very few. Thus, the rank/abundance plot (or whittaker plot), allows a graphic representation of relative abundance by assigning ranks to species from the most to the least abundant, representing the abundance in a percentage or logarithmic scale (Magurran 2004).

3.4.5. Unique species

It is important to evaluate which methods are able to detect the rarest, most elusive or cryptic species, not only in detecting different taxa, as aforementioned species within the taxa have very different behaviour and habits. Therefore, it was analysed which species had been detected between 1 and 3 times and which methods had detected them, being successful in detecting the theoretically scarcest species in terms of abundancy.

4. Results

The individuals recorded during the fieldwork are represented in the Table 1, showing all the species and individuals recorded. Thirty-one species were detected, and they are described in Appendix 1.

Table 1. Number of individuals and species detected during the data collection for the different methods: Visual Transect (VT), Stoning Transect (ST), Fibroscope Transects (FT), Pitfall Traps (PT), Coverboards (Cb) and Free Search (FS).

	VT	ST	FT	PT	CB	FS	Total
Agama atra	0	0	0	0	0	2	2
Agama aculeata	1	0	0	0	0	0	1
Agama anchietae	1	0	0	0	0	6	7
Trachylepis sulcata	38	0	0	0	0	56	94
Trachylepis variegata	29	1	0	1	0	54	85
Trachylepis occidentalis	1	0	0	0	0	2	3
Acontias tristis	0	0	0	0	0	3	3
Chondrodactylus angulifer	5	0	0	1	0	9	15
Chondrodactylus bibronii	13	1	0	3	0	63	80
Goggia lineata	2	0	0	0	0	0	2
Lygodactylus bradfieldi	6	0	0	0	0	8	14
Pachydactylus montanus	32	4	0	0	0	54	90
Pachydactylus punctatus	0	0	0	0	0	1	1
Pachydactylus rugosus	1	0	0	0	0	1	2
Ptenopus garrulus	0	0	0	0	0	17	17
Meroles suborbitalis	20	0	0	0	0	6	26
Pedioplanis inornata	18	0	0	0	0	42	60
Pedioplanis lineoocellata	2	0	0	0	0	1	3
Pedioplanis namaquensis	3	0	0	0	0	2	5
Nucras tessellata	1	0	0	0	0	0	1
Cordylosaurus subtessellatus	0	2	0	0	0	1	3
Platysaurus attenboroughi	1	0	0	0	0	0	1
Bitis caudalis	2	1	0	0	0	4	7
Bitis xeropaga	0	0	0	0	0	1	1
Telescopus beetzii	1	0	0	0	0	0	1
Psammophis notostictus	1	0	0	0	0	1	2
Psammophis trigrammus	1	0	0	0	0	0	1
Prosymna frontalis	1	0	0	1	0	0	2
Naja nivea	1	0	0	0	0	0	1
Namibiana occidentalis	0	0	0	2	0	1	3
Rhinotyphlops lalandei	0	0	0	1	0	2	3
Total	**181**	**9**	**0**	**9**	**0**	**337**	**536**
Number of sampling units	**198**	**77**	**37**	**88**	**88**	**66**	**71**

In addition to the species represented, two amphibian species were found in the Orange River by active visual and auditory search, which were also detected by AudioMoth devices. These species are *Amietia delalandii* (Duméril and Bibron, 1841) and *Sclerophrys gutturalis* (Power, 1927). In the case of *A. delalandii* numerous individuals were found in larval stage, which were identified by morphological characteristics: shape, tail, colour, nostrils, spiracle position, mouth and LTRF (Labial Tooth Row Formula).

However, amphibians will not be represented in the results due to the complete difference in counting and detection method, and different taxonomic group from the others, being only possible to detect in the reduced area of the Orange River. Thus, the results are focused only on reptiles. Reptile individuals are represented on Figure 12.

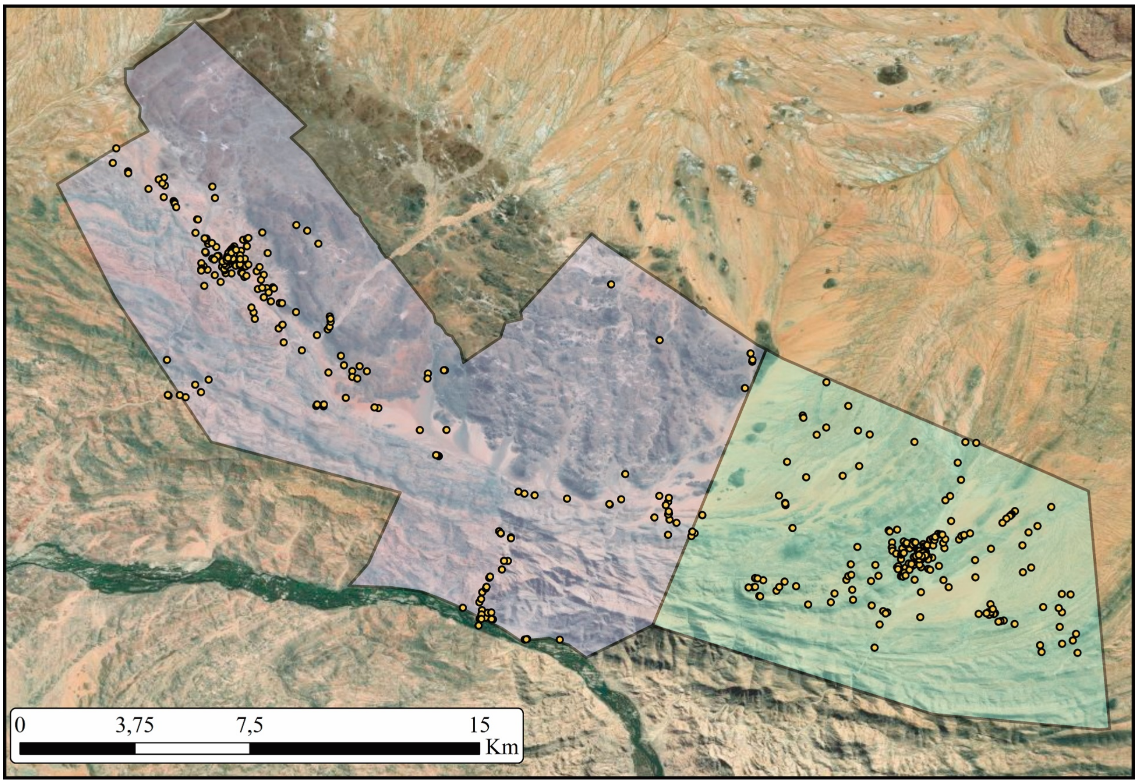


Figure 12. Representation of the individuals found in the present study along the study area.

Figure 13 represents the number of species obtained in the present study, those obtained by Theart et al. in 2018 (unpublished), a total sum of the species registered by both studies summed up, in which the 10 species detected by Theart et al. (unpublished) but not in the study were added, and in addition, the maximum number of species expected from distribution maps and literature studied before the fieldwork.

Moreover, apart from the species included in the total of the present study and previous work, Nile monitor (*Varanus niloticus* (Linnaeus, 1766)) has been detected in the study area by other people, showing photographic evidence. Karasburg tree skink (*Trachylepis sparsa* (Mertens, 1954)) was detected by the research team in the surroundings but not inside the study area. There are also other species that have not been detected in the study area but in the proximities as Namaqua chameleon (*Chamaeleo namaquensis* Smith, 1831) and rock monitor (*Varanus albigularis* (Daudin, 1802)), and also, in more distant areas, leopard tortoise (*Stigmochelys pardalis* (Bell, 1828)).

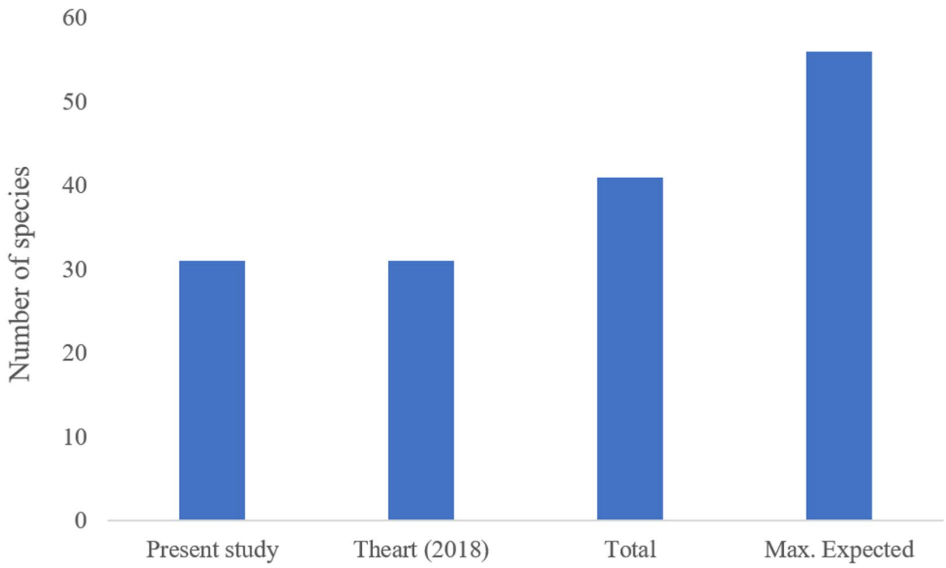


Figure 13. Representation of the species registered in the present study and previous work (Theart et al. unpublished), the total species registered combining both studies, and the maximum species expected based on the distribution maps and literature.

4.1. Accumulation curves, asymptotic species richness estimators and rarefaction curves

The total accumulation curve is represented in Figure 14. All the methods together are represented, by working days as sampling units. A total of 31 species were detected during the fieldwork period. The overall species count has low number of singletons, so 95 % Confident Interval (CI) of the SBR curve is also low, with a range of 25.61 to 36.39. The estimators obtained results of 37.39 species richness according to Chao1 estimator and 37.56 according to ACE estimator. The accumulation curve of the estimators and the SBR curve are reaching the asymptote, also reaching the point of stability for the asymptotic estimators and thus a constant species richness value for the study.

With these results, a total sampling efficiency of 82.91 % according to Chao1 and 82.53 % according to ACE were calculated.

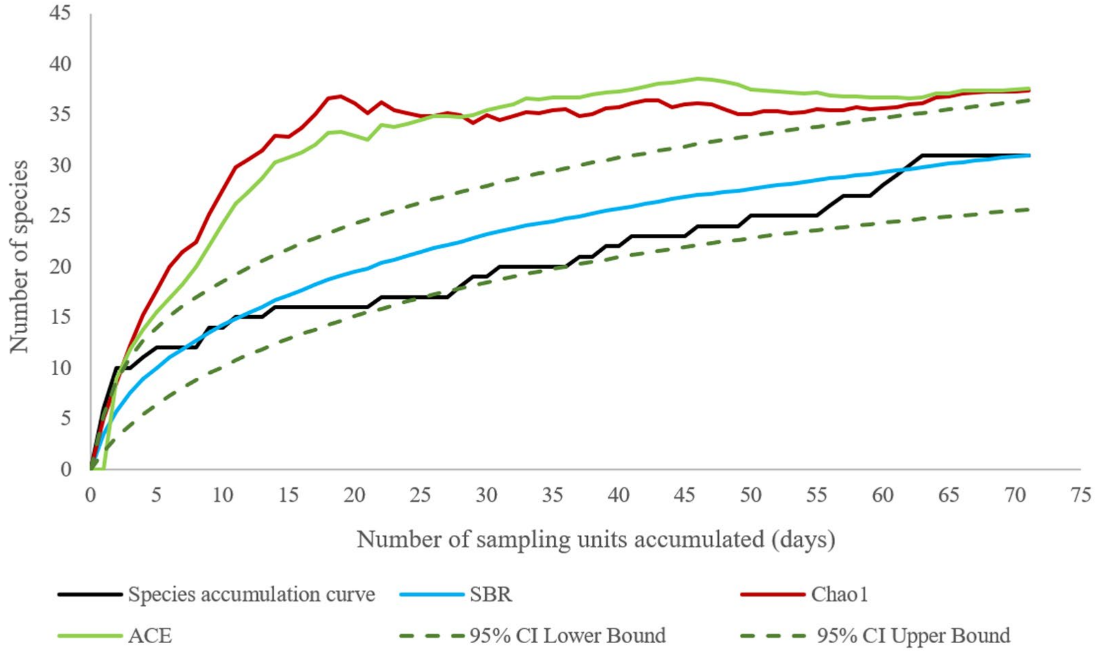


Figure 14. Representation of the total species accumulation curve, SBR curve and asymptotic estimators for all methods together.

4.1.1. Active methods

Visual Transects - The accumulation curve of the Visual Transects was represented in the Figure 15, with a detected species richness of 23, and an estimate of 43.06 with the Chao1 estimator and 45.25 according to the ACE estimator. Due to the large number of singletons (uniques) in this method, 95 % CI of the SBR curve ranged from 15.66 to 30.24, a quite wide range. The accumulation curve of the estimators is far from the species accumulation and SBR curves. It can be seen that the asymptote in the SBR curve has not yet been reached and therefore the asymptotic estimators are not stabilized.

The sampling efficiency calculation for Visual Transects was 53.41 % using the Chao1 estimator and 50.83 % with ACE.

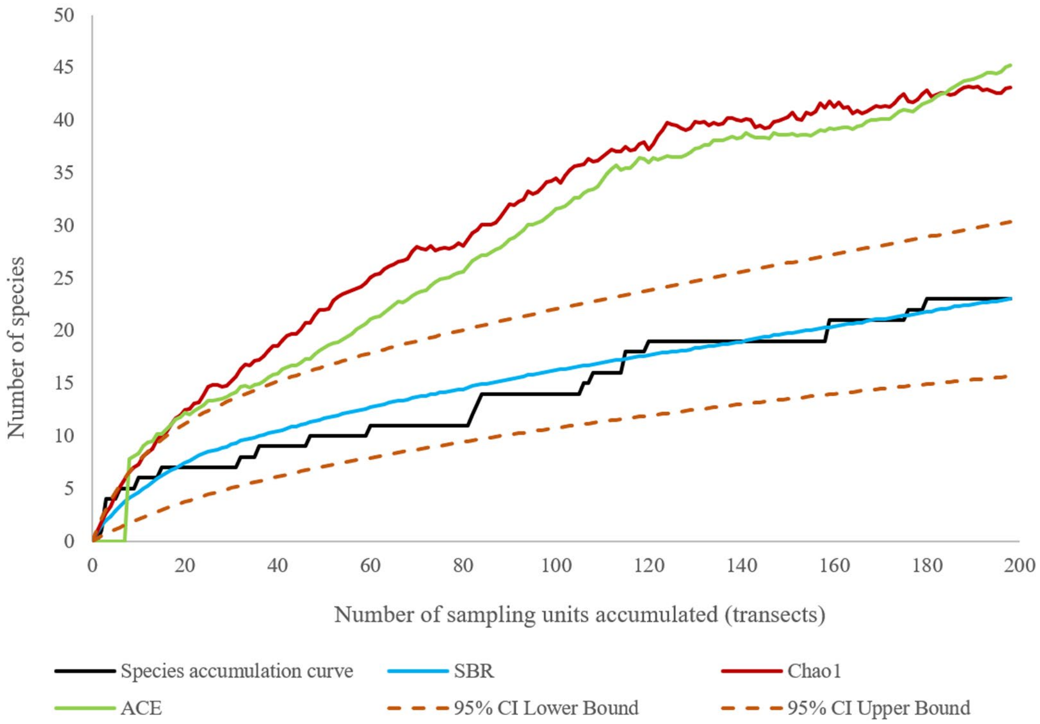


Figure 15. Representation of species accumulation curve, SBR curve and asymptotic estimators for Visual Transects.

Stoning Transects - The species accumulation curve for the Stoning Transects had a total of 5 species detected during the sampling period. The Chao1 estimator obtained a result of 9.00 species. Most of the observed species were detected on only one occasion, so 95 % CI of the SBR curve ranged from 8.01 to 9.44. This also makes the ACE estimator undefined and cannot be properly calculated, so only Chao1 was used for this method. In the Figure 16, it can be seen that the graphical representation of Chao1 is close to the accumulation curve but is separated by advancing the number of transects. With the number of samples made, it can be seen that the graph is far from reaching the asymptote and the estimator is not stabilized, thus the value for the species richness is still too variable.

The sampling efficiency of Stoning Transects was 55.56 % based on Chao1 estimation.

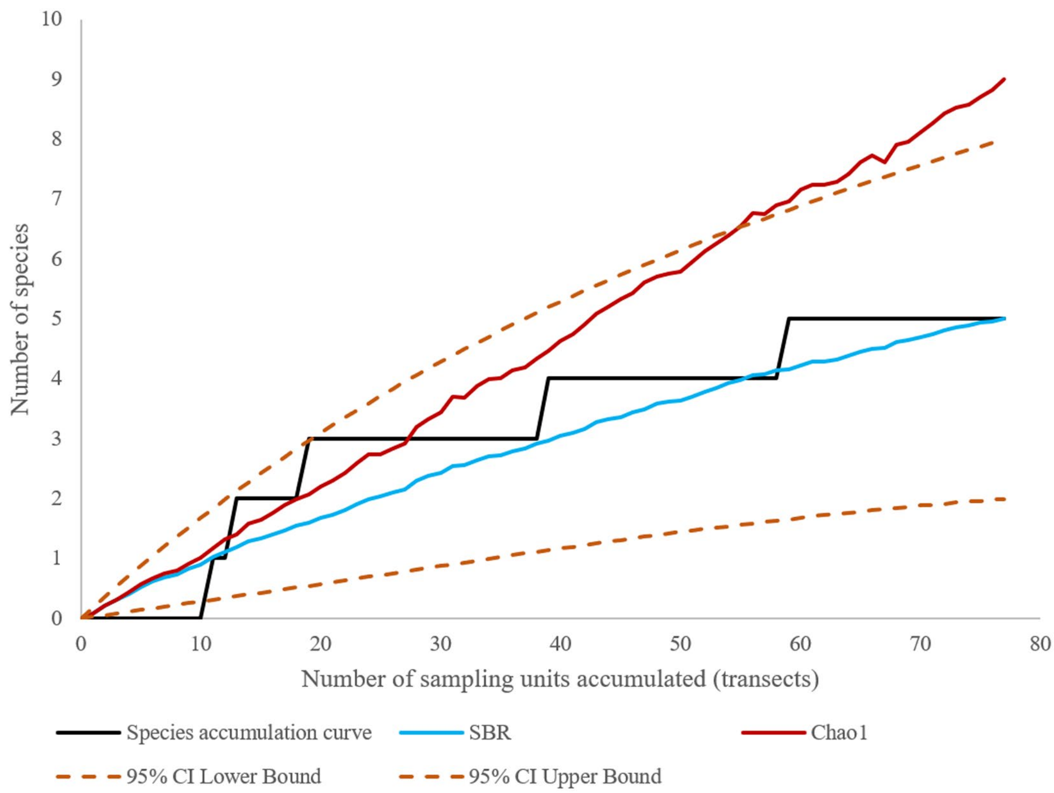


Figure 16. Representation of species accumulation curve, SBR curve and Chao1 estimator for Stoning Transects.

Fibroscope Transects - For this method, the accumulation curve could not be represented, since no individual of any species was detected during the sampling period, so the estimators cannot be calculated either, resulting in a null value for both the detected species richness, and no estimation being possible. The efficiency of this method was therefore 0 %.

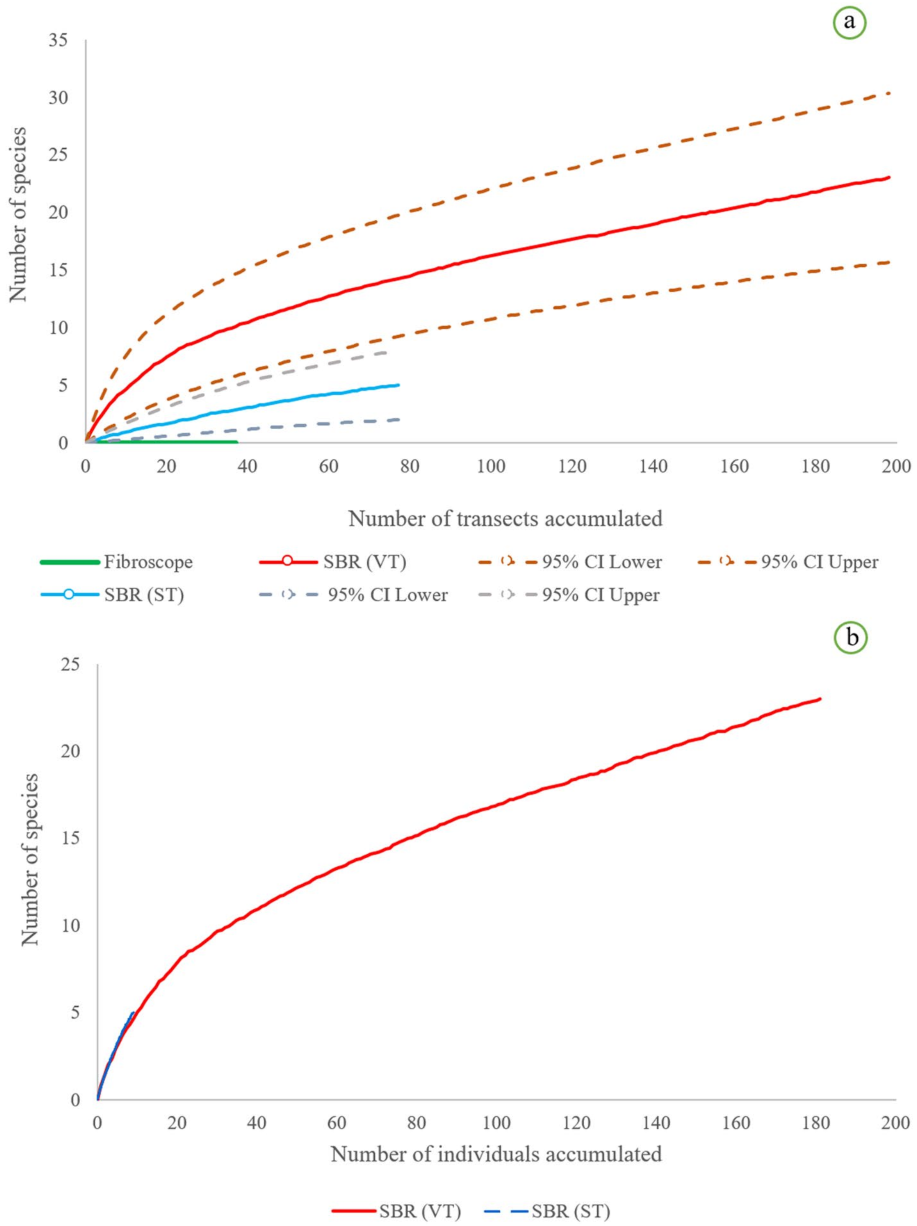


Figure 17. Comparison of SBR curves of active methods:
a) Based on transects accumulated. b) Based on individuals accumulated.

With the rarefaction curves it was possible to make comparisons of the effectiveness of these methods. In Figure 17a, it can be seen that the Visual Transects method had a higher efficiency than the one represented by Stoning and Fibroscope, without the confidence intervals overlapping. Re-scaling was also performed on accumulated individuals, shown in Figure 17b, showing that Stoning Transect described a similar efficacy to Visual Transect in terms of species found by detected individuals. However, the small number of individuals found by the Stoning method makes this comparison difficult. This is because this type of comparison does not consider the difference in effort for finding the individuals.

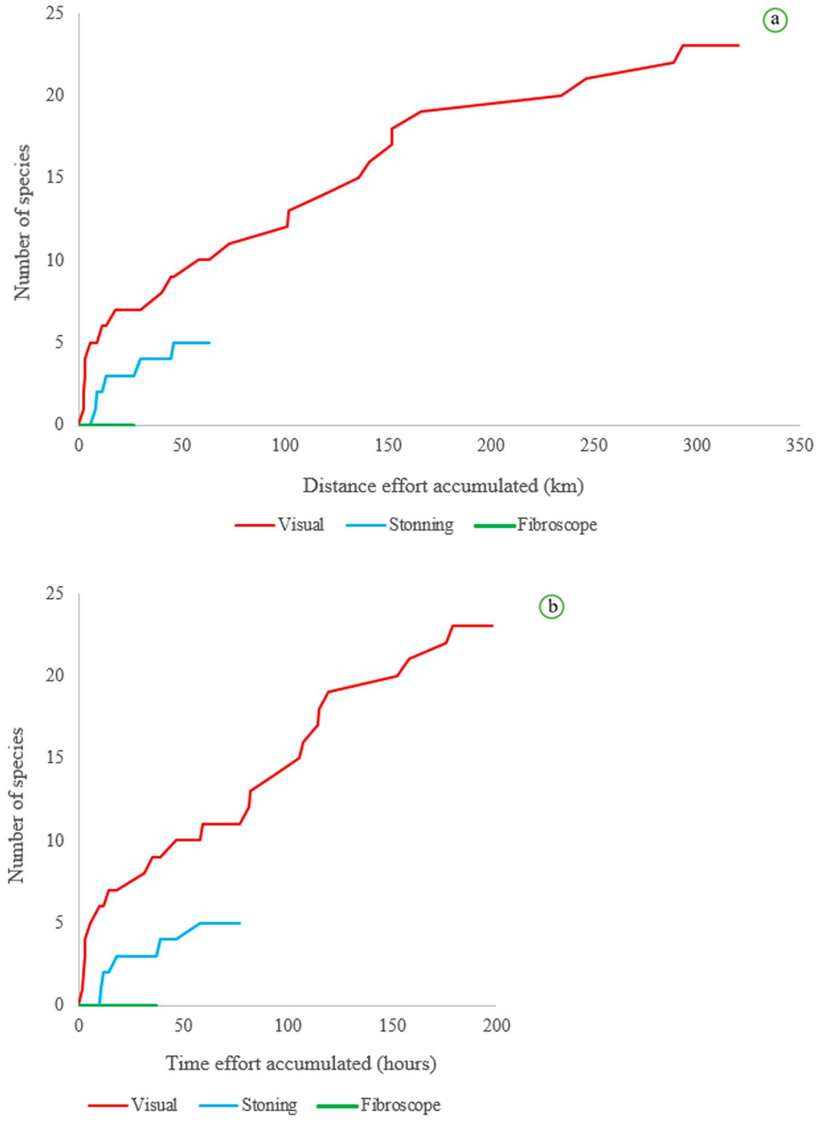


Figure 18. Comparison of species accumulation curves for active methods: a) based on distance effort. b) based on time effort.

On the other hand, the recording of the individuals and the transects, allows the calculation of the sampling effort by distance until the different species are obtained, making accumulation curves with km as sample units, and comparing it with de accumulation curve based on transects (Figure 18), which represent the effort in terms of time, being one hour transects.

Fibroscope Transects had a total effort of 26.63 km with 0 species detected. The total effort in distance for Visual Transects was 320.10 km while for Stoning Transects it was 63.42 km. It can be seen in Figure 18 that the total effort in terms of distance was greater than the effort measured in hours for Visual Transects, while the opposite occurred for the other two methods. However, the detection of species with respect to the effort made follows an accumulation curve in which the Visual Transects were still more effective for the range represented.

4.1.2. Passive methods

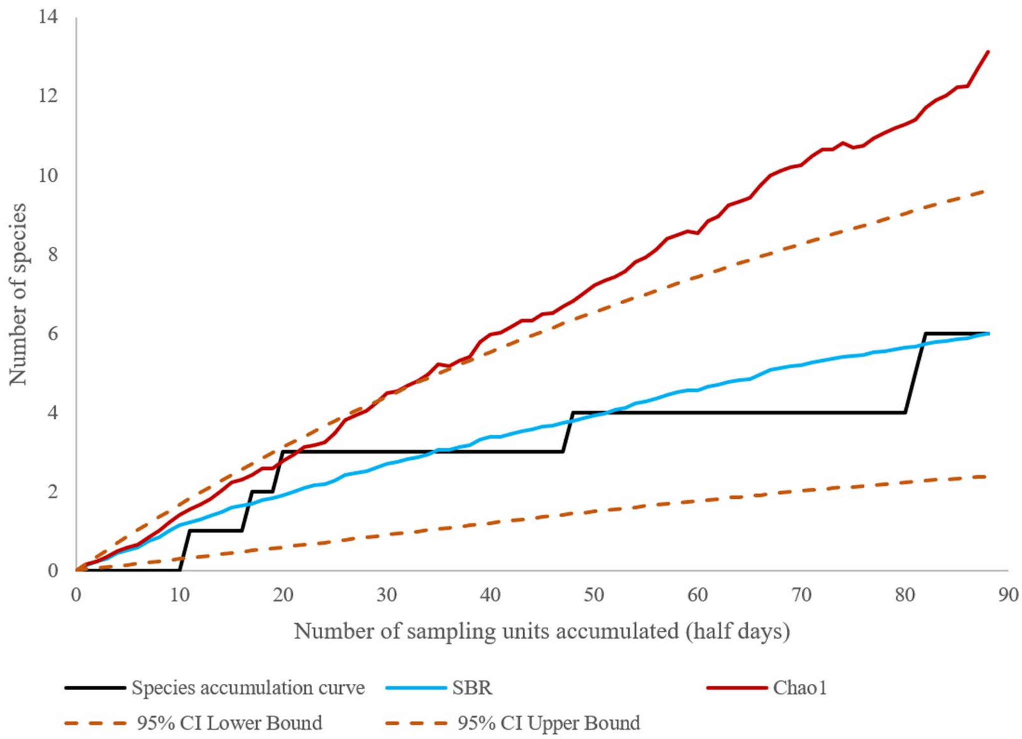


Figure 19. Representation of species accumulation curve, SBR curve and Chao1 estimator for Pitfall Traps.

Pitfall Traps - The species accumulation curve for Pitfall Traps shows a total of 6 detected species. Most of the detected species were singletons, so 95 % CI of the rarefaction curve is wide with a range of 2.38 to 9.62, and the ACE estimator was not used. The Chao1 estimator obtained a result of 13.11 species. The representation of Chao1 and the rarefaction curve was similar to the Stoning Transects curves, increasing the distance between them by increasing the sampling units, placing the graph in an insufficient number of samples to achieve the asymptote and stability of the estimators. (Figure 19).

The sampling efficiency for this method was 45.77 % based on the value estimated by Chao1.

Coverboards - As in the case of the Fibroscope Transects, this method detected 0 individuals during the fieldwork, so in the same way no estimator could be calculated, being a value 0 for the detected richness and a null efficiency.

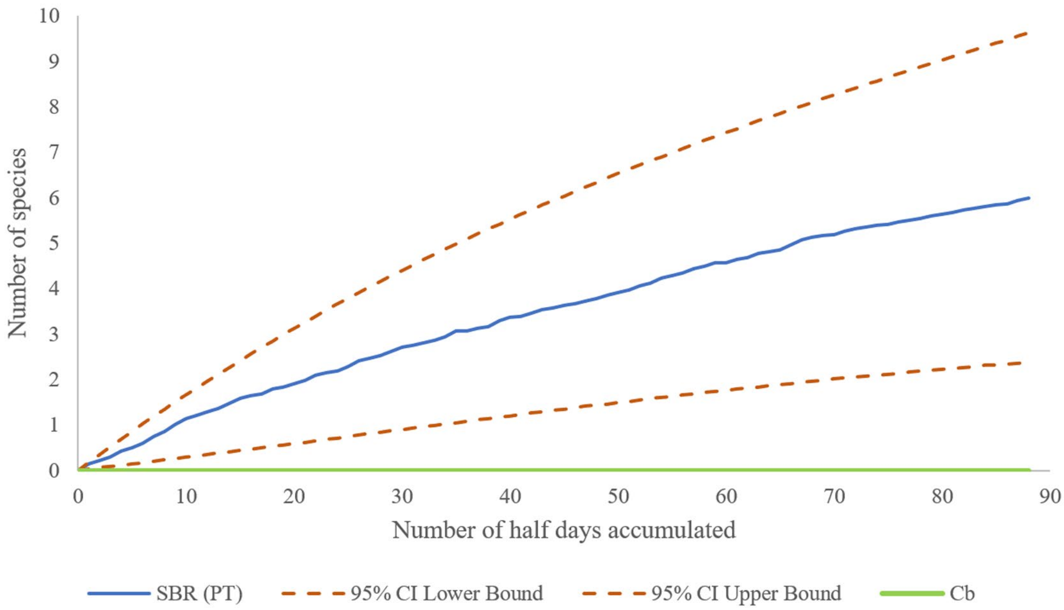


Figure 20. Comparison of SBR curves of the passive methods.

As in the active methods, since they have the same sample units, these passive methods can be compared in terms of effectiveness through their SBR curves (Figure 20). However, this comparison is obvious as no species have been detected through the Coverboards method.

4.1.3. Other methods – Free Search

In this method 23 species of reptiles were detected, and although there are several singletons detected, they are less than in other methods so 95 % CI has a range of 18.72 to 27.28, lower than in the rest of the methods. The Chao1 estimator obtained a result of 29.11 species, while ACE estimated 31.01. The accumulation curve of the estimators is far from the SBR curve, but it can be seen how they approach the area of the graph with the highest sampling units, at which time it is reaching the asymptote, but still not completely, and therefore the asymptotic estimators are not yet totally stabilized (Figure 21).

With these results, the estimated sampling efficiency is 79.01 % based on Chao1 and 74.17 % based on ACE.

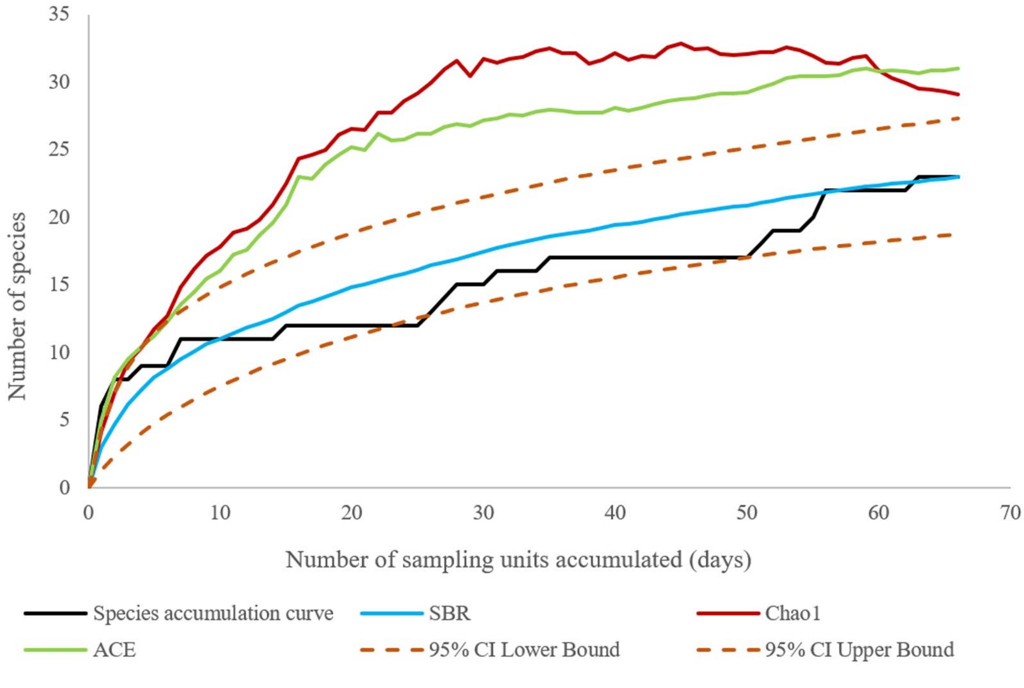


Figure 21. Representation of species accumulation curve, SBR curve and asymptotic estimators for Free Search.

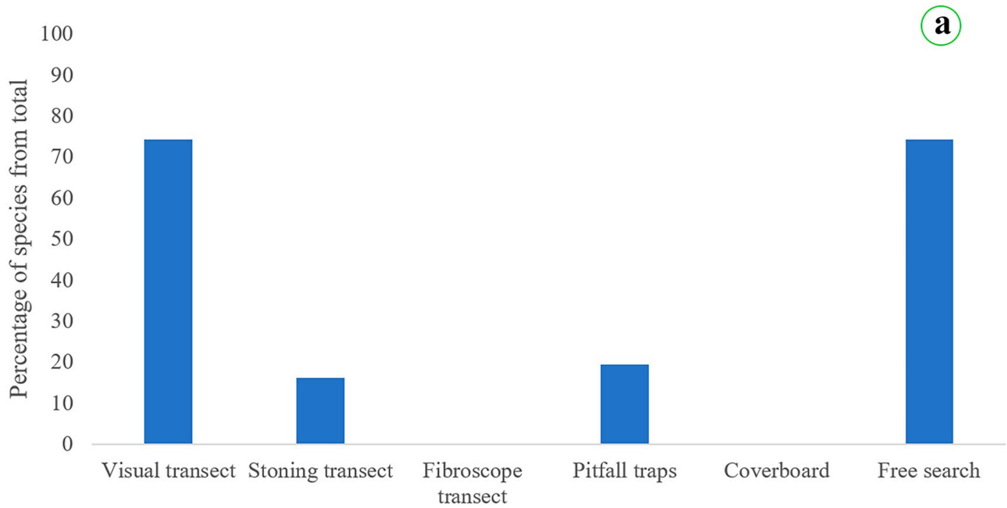
4.2. Species detected, individuals detected and capture rates

The number of samples (transects, half days and days), species and individuals detected during the fieldwork were represented and captures rates were calculated (Table 2). Total capture rates were 7.55 individuals per day and 0.44 species per day.

Table 2. Summary table of individuals, species, and capture rates per sampling unit.

	Visual Transect	Stoning Transect	Fibroscope Transect	Pitfall Traps	Coverboard	Free Search	Total
Samples	198	77	37	88	88	66	71
Individuals	181	9	0	9	0	337	536
Individual capture rate	0.91	0.12	0	0.10	0	5.11	7.55
Species	23	5	0	6	0	23	9
Species capture rate	0.12	0.07	0	0.07	0	0.35	0.44

For the comparison between methods, the species detected, and species detected separated by the different groups were represented in percentual proportion from the total number of species and total number of species per each group (Figure 22).



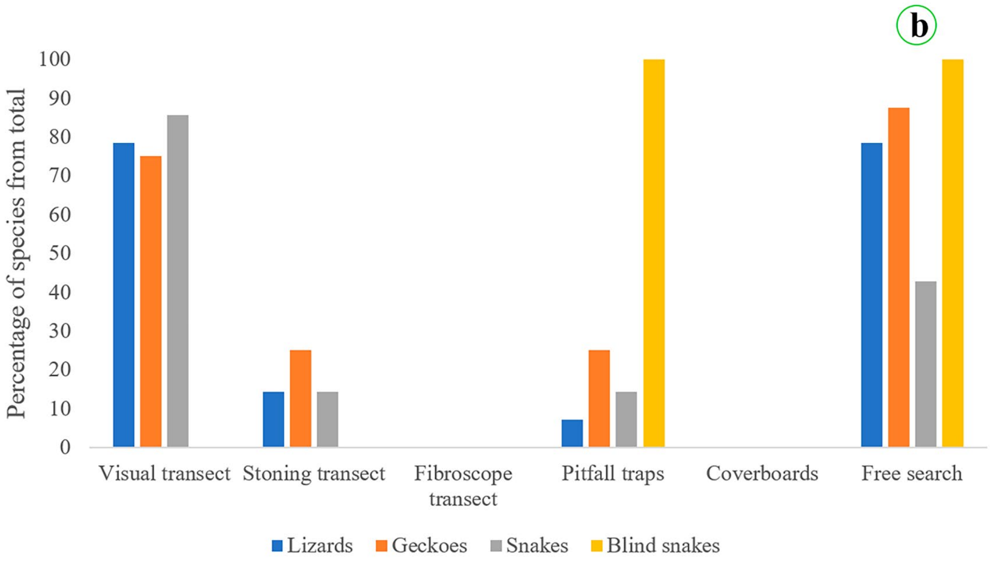
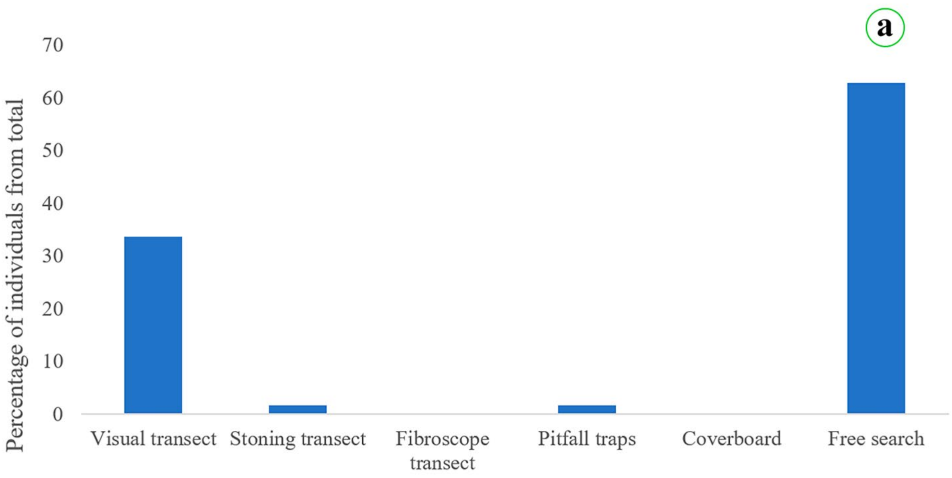


Figure 22. Percentage of species detected per method:
a) from total number of detected species. b) from species total by group.



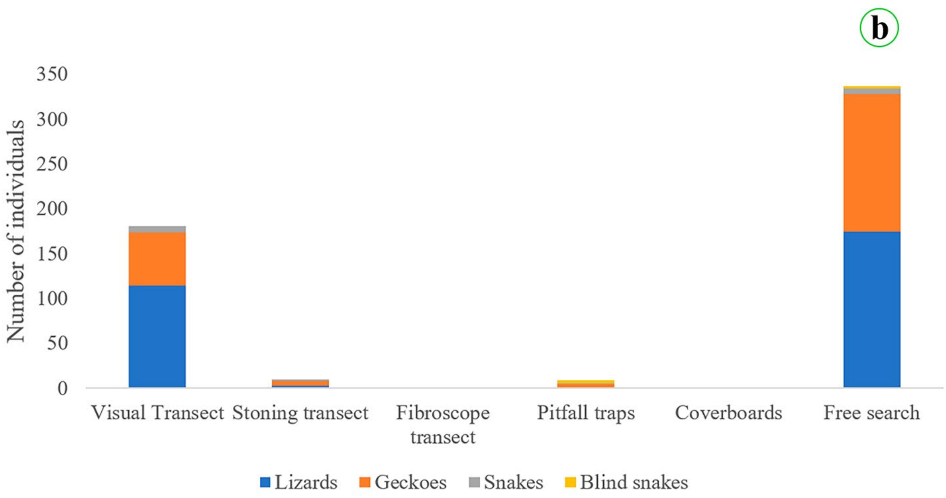


Figure 23. Individuals detected per method: a) Percentage of individuals detected from total number. b) Number of individuals detected by group.

The same was calculated regarding the individuals, showing the percentual proportion of individuals from total per method and the number of individuals detected separated by groups on Figure 23.

4.2.1. Active methods

Visual Transects – This method detected a total of 23 species, covering 74.19 % of the 31 totals (Figure 22a). The species detected by this method belong to the Lizards, Geckoes and Snakes groups, having a great efficacy in their capture, being more than 70 % of the Lizards and Geckoes species and more than 85 % of the Snakes, those detected by the Visual Transects (Figure 22b). The capture rate of species per transect is 0.12 (Table 2).

Regarding the individuals, a total of 181 were detected, corresponding to 33.77 % of the total number of individuals (Figure 23a), with a capture rate of 0.91 individuals per transect (Table 2). From the individuals detected by Visual Transects, as indicated in the Figure 23b, 115 were Lizards, 59 Geckoes and 7 Snakes, showing a great efficiency for the detection of the first two groups.

Stoning Transects – This method detected 5 species, being 16.00 % of the total species as shown in the Figure 22a. The detected species belong to the Lizards, Geckoes and Snakes groups as in the case of Visual Transects, but with a much lower percentage of species covered by this method, with 14.28 % of Lizards and Snakes species detected and 25.00 % of Geckoes as shown in the Figure 22b. The species capture rate is also much lower, with 0.07 species per transect (Table 2).

Regarding individuals, 9 individuals were detected, being 1.68 % of the individuals detected (Figure 23a), with a capture rate of 0.12 individuals per transect (Table 2). Of the individuals detected, 3 individuals of the Lizards group, 5 of Geckoes and 1 of Snakes are represented in the Figure 23b, which indicates a low general effectiveness, which is slightly higher for the detection of gekkonids.

Fibroscope Transects - As with the previous methods, the species and individuals detected have been represented in the different figures, but in this case they are 0 for both, with a null capture rate as well, due to the absence of detection of any species through this method.

4.2.2. Passive methods

Pitfall Traps - This method detected 6 species, representing 19.35 % of the total species, as shown in the Figure 22a. The detection included species from all groups, covering 7.14 % of Lizard species, 25.00 % of Geckoes, 14.28 % of Snakes and 100 % of Blind Snakes species detected, being highly effective for the last group (Figure 22b). The capture rate of species in relation to the number of times checked, or that is the same as half days, was 0.07 species for each half day (Table 2).

As for the capture of individuals, a total of 9 were detected, representing 1.68 % of the total (Figure 23a). The capture rate was 0.10 individuals per half-day (Table 2). Of the 9 individuals, 1 belonged to the Lizards group, 4 to Geckoes, 1 to Snakes and 3 to Blind Snakes (Figure 23b). The efficiency in terms of capture of individuals is low with a higher detection for the groups of Geckoes and Blind Snakes.

Coverboards - This method was totally inefficient in the capture of individuals or species (Figures 21, 22), obtaining a null detection during the 88 half days in which the passive methods were working.

4.2.3. Other methods – Free Search

Twenty-three species were detected with the methods included in Free Search, covering 74.19 % of the 31 total (Figure 22a). The species detected by this method belong to all groups, covering 78.57 % of Lizards, 87.50 % of Geckoes, 100 % of Blind Snakes, while for Snakes this percentage is lower, with 42.88 % (Figure 22b), being highly effective for all groups except Snakes. The capture rate is 0.35 species per day (Table 2).

Regarding individuals, a total of 337 were detected, corresponding to 62.87 % of the total individuals (Figure 23a), with a capture rate of 5.11 individuals per day (Table 2). Of the individuals detected by Free Search, as represented in the Figure 23b, 175 were Lizards, 153 Geckoes, 6 Snakes and 3 Blind Snakes, showing a great efficiency for the detection of Lizards and Geckoes.

4.3. Species - specific methods

A matrix of shared species between methods is shown in Table 3. It represents the number and the percentage of species shared between methods calculated from the total species summed up by both groups.

Table 3. Matrix of shared species. Percentage of shared species and number of shared species are represented.

	VT	ST	FT	PT	Cb	FS
VT		16.67	0	16.00	0	45.16
ST	4		0	22.22	0	21.74
FT	0	0		0	0	0
PT	4	2	0		0	20.83
Cb	0	0	0	0		0
FS	14	5	0	5	0	

% of shared species

Number of shared species

The species shared between Visual Transects and Stoning Transects are 4, a 16.67 % of the total species adding both methods, a value very similar to the species shared between Visual Transects and Pitfall Traps. Slightly higher values are the result of species shared between Pitfall Traps and Stoning Transects, and Pitfall Traps and Free Search. The highest percentage of shared species occurs between Visual Transect and Free Search, being 45.16 %, due to 14 shared species, being still a value lower than 50 %.

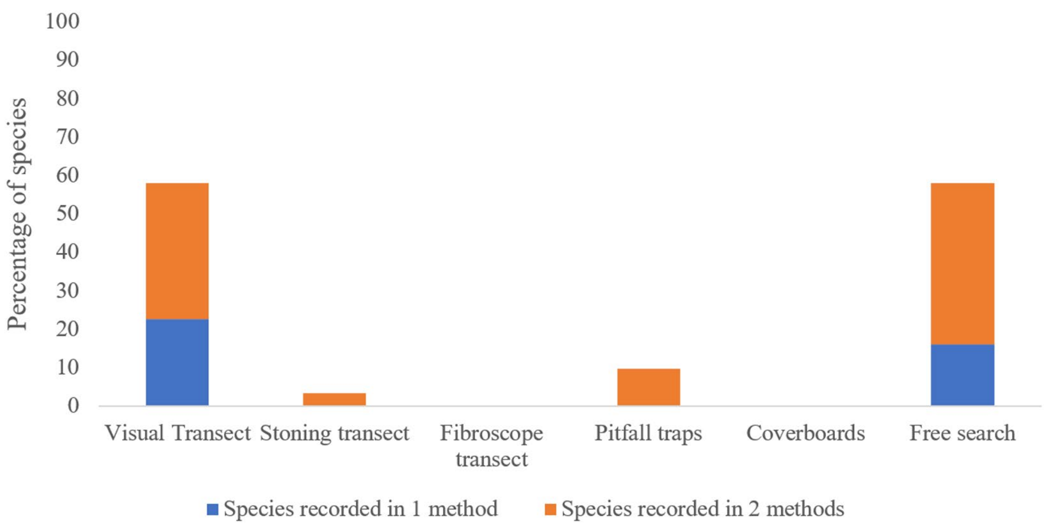


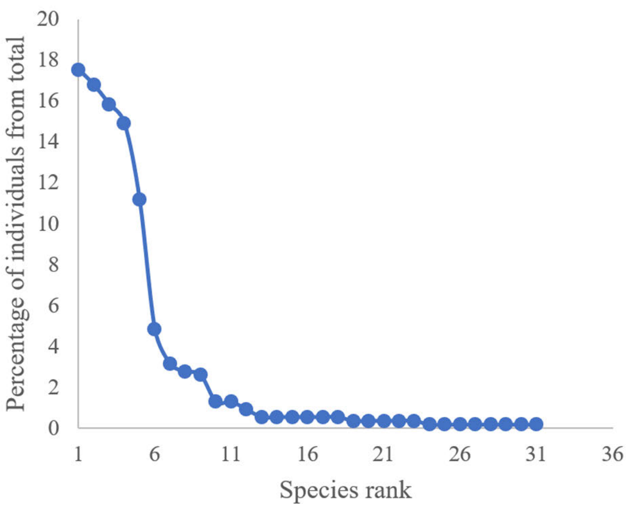
Figure 24. Percentage of species detected in 1 or 2 methods from total number of species.

In contrast, the Figure 24 shows the species records detected by one and two methods. The species detected by one method are recorded by Visual Transects, with 22.58 % of the 31 total species, and by Free Search, with 16.13 %.

The species detected by two methods are distributed among the different methods, being mostly detected by Visual Transects and Free Search, but also by Pitfall Traps and Stoning Transects.

4.4. Rank/abundance plot

The rank/abundance of the entire survey is shown in the Figure 25. There are 5 species with a higher abundance than the rest. Most individuals are represented by the 4 species of ranks 1 - 4, which exceed 14 % each, adding together more than 65 % of the individuals in the sampling, and adding the next species per rank, the 76.30 %. These species are *Trachylepis sucalta*, *Pachydactylus montanus*, *T. variegata*, *Chondrodactylus bibronii* and *Pedioplanis inornata*, which indicates a very irregular distribution of individuals among the species detected, with a few species abundantly detected and many with scarce detections.

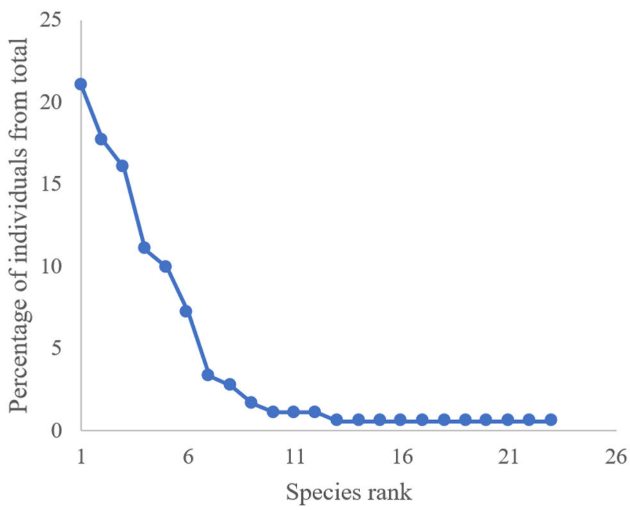


Species	Rank
Trachylepis sulcata	1
Pachydactylus montanus	2
Trachylepis variegata	3
Chondrodactylus bibronii	4
Pedioplanis inornata	5
Meroles suborbitalis	6
Ptenopus garrulus	7
Chondrodactylus angulifer	8
Lygodactylus bradfieldi	9
Agama anchietae	10
Bitis caudalis	11
Pedioplanis namaquensis	12
Trachylepis occidentalis	13

Figure 25. Rank/abundance plot for total survey. In the table there are represented the 13 most abundant species.

4.4.1. Active methods

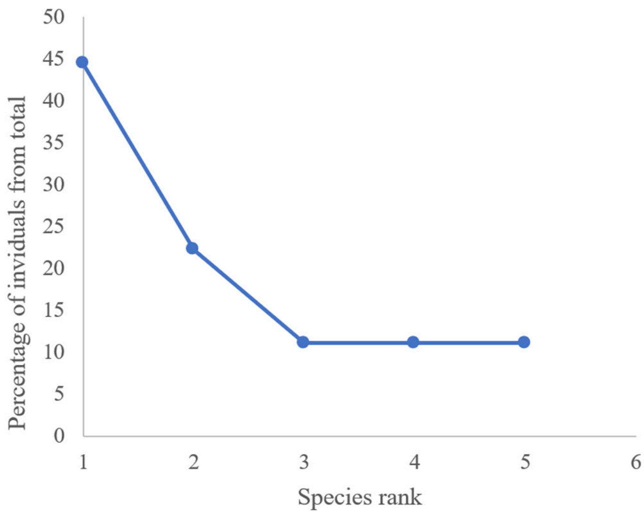
Visual Transects - Figure 26 shows the rank/abundance plot of the Visual Transects. It can be observed that there are 6 abundant species and more rare species, with a marked gradient of 3 species representing more than 15 % of the sample each. Thus, almost 50 % of the individuals detected by this method belong to the species *Trachylepis sulcata*, *Pachydactylus montanus* and *T. variegata*.



Species	Rank
Trachylepis sulcata	1
Pachydactylus montanus	2
Trachylepis variegata	3
Meroles suborbitalis	4
Pedioplanis inornata	5
Chondrodactylus bibronii	6
Lygodactylus bradfieldi	7
Chondrodactylus angulifer	8
Pedioplanis namaquensis	9
Goggia lineata	10
Pedioplanis lineoocellata	11
Bitis caudalis	12

Figure 26. Rank/abundance plot for Visual Transects. In the table there are represented the species with more than 1 record by this method.

Stoning Transects - In the Figure 27 it can see seen the rank/abundance plot of the Stoning Transects. In this case, we see that there is clearly a very marked abundance of the rank 1 species, being the one that detected the most individuals by this method, with 44.44 %, followed by the rank 2 species which accounts for 22.22 % of the total individuals. These two species are *Pachydactylus montanus* and *Cordylosaurus subtesellatus*.



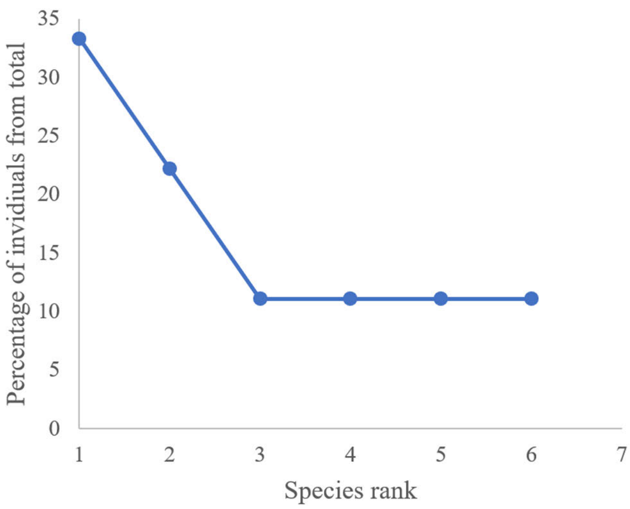
Species	Rank
Pachydactylus montanus	1
Cordylosaurus subtessellatus	2
Trachylepis variegata	3
Chondrodactylus bibronii	4
Bitis caudalis	5

Figure 27. Rank/abundance plot for Stoning Transects. In the table there are represented the species detected by the method.

Fibroscope Transects - For this method, the rank/abundance plot could not be represented due to the absence of detections.

4.4.2. Passive methods

Pitfall Traps - In this method the rank/abundance plot (Figure 28) is similar to the Stoning Transects in a less marked way, also with two species of dominant abundance, with 33.33 % and 22.22 %, belonging to *Chondrodactylus bibronii* and *Namibiana occidentalis*.



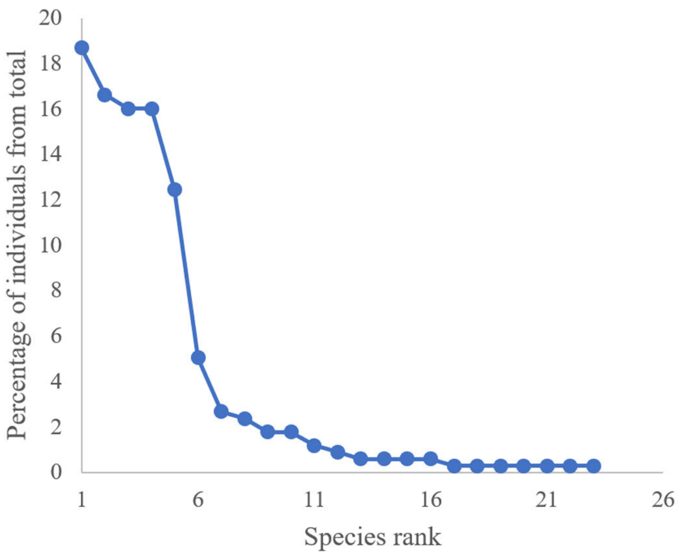
Species	Rank
Chondrodactylus bibronii	1
Namibiana occidentalis	2
Trachylepis variegata	3
Chondrodactylus angulifer	4
Prosymna frontalis	5
Rhinotyphlops lalandei	6

Figure 28. Rank/abundance plot for Pitfall Traps. In the table there are represented the species detected by the method.

Coverboards - As with the Fibroscope Transect method, it is not possible to represent a rank/abundance plot in this case.

4.4.3. Other methods – Free Search

The rank/abundance plot represented for this method (Figure 29) is similar to that of Visual Transects, with 6 species with a higher abundance than the rest, especially highlighted in the species with ranks 1 - 4, which have an abundance of more than 16 % of the individuals detected by Free Search each, adding up to more than 60 % of the individuals in the sample represented by those 4 species, which are *Chondrodactylus bibronii*, *Trachylepis sulcata*, *T. variegata* and *Pachydactylus montanus*.



Species	Rank
Chondrodactylus bibronii	1
Trachylepis sulcata	2
Trachylepis variegata	3
Pachydactylus montanus	4
Pedioplanis inornata	5
Ptenopus garrulus	6
Chondrodactylus angulifer	7
Lygodactylus bradfieldi	8
Agama anchietae	9
Meroles suborbitalis	10
Bitis caudalis	11
Acontias tristis	12
Agama atra	13
Trachylepis occidentalis	14
Pedioplanis namaquensis	15
Rhinotyphlops lalandei	16

Figure 29. Rank/abundance plot for Free Search. In the table there are represented the species with more than 1 record by this method.

4.5. Unique species

In the group of species with scarce detections, visible in the total rank/abundance plot, there are some species with only one, two or three individuals detected. These data are events of great importance since there is a detection of species that would not have been added in the absence of a very small number of events.

The Figure 30 shows these species that have been detected between one and three times. There are 8 species with a single sampling event, of which 6 were detected by Visual Transects and 2 by Free Search. 11 species were detected two or three times, 6 of them detected by Visual Transects, 1 by Stoning Transects, 3 by Pitfall Traps and 9 by Free Search.

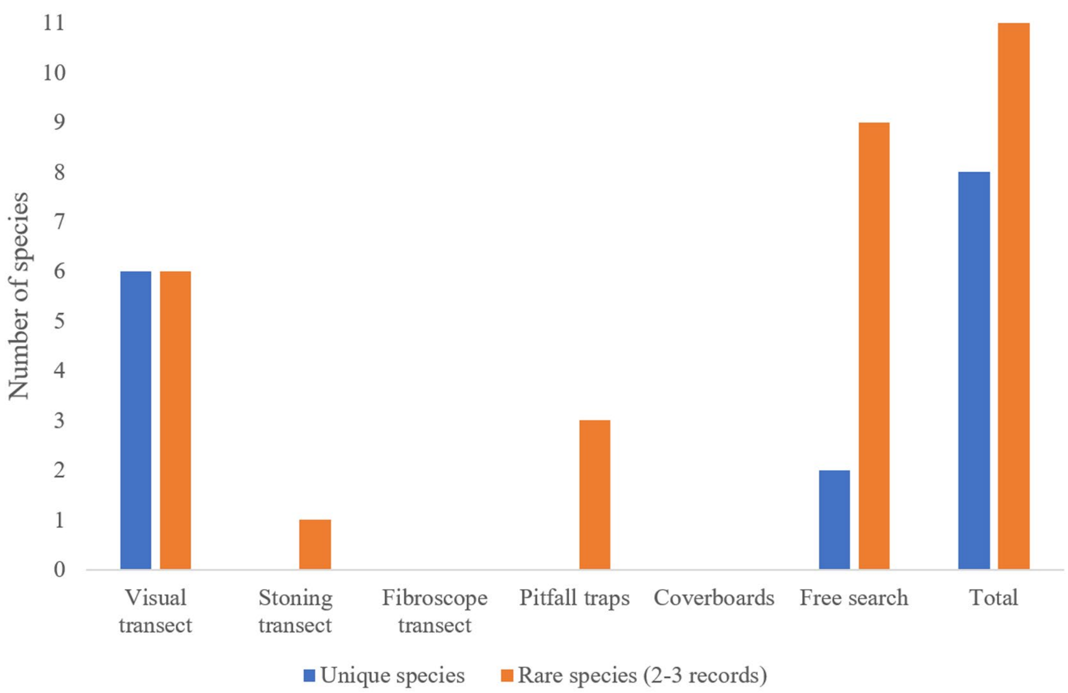


Figure 30. Species detected 1-3 times represented by method.

5. Discussion

The results show a total of 31 species of reptiles and 2 amphibians detected, with 23 reptile species detected by the Free Search and Visual Transects methods, 5 by Stoning Transects, and 6 by Pitfall Traps during an active sampling period of 71 days, with a total of 536 individuals detected. 2 amphibian species were detected by Free Search and AudioMoth devices, but they will not be discussed further since the sample size is low and it lacks standardization. The general efficacy of the survey was of 82.53 - 82.91 % of the species detected from total species richness estimated by asymptotic estimators. The capture rates of 0.44 species per day and 7.55 individuals per day (Table 2), reflects Theart et al. (unpublished) conclusion, in which they defined this area as one of high biodiversity but low abundance. The rank/abundance plots represented for the different sampling methods and total survey, reflects accurately this, with a large number of species with few records and 76.3 % of individuals represented by *Trachylepis sulcata*, *Pachydactylus montanus*, *T. variegata*, *Chondrodactylus bibronii* and *Pedioplanis inornata*. The quantitative comparison carried out by SBR curves and species richness estimators only allows the comparison of efficacy between methods belonging to the same group, with the result of Visual Transects as the most effective active method and Pitfall Traps as the most effective passive method.

Our data suggest that a combination of different sampling methods is necessary to obtain a complete species inventory and picture of all the taxa that inhabit the area. This idea was also concluded in other studies (Todd et al. 2007; Hutchens and DePerno 2009), being an idea increasingly established in herpetological studies that only a set of methods is likely to obtain a species richness closer to reality.

Nevertheless, although a set of methods is necessary, our results showed there are some methods that are more effective than others. There are some non-specific methods that capture many individuals from different species and taxa, as Visual Transects or Free Search (Garden et al. 2007; Sung et al. 2011) while other are more specific and detect only certain taxa or species like Pitfall Traps or Stoning Transects (Garden et al. 2007; Henderson et al. 2016), thus is not important the range of species but also considering the different taxa (Rödel & Ernst 2004).

In the current study, Visual Transects and Free Search detected the largest number of individuals and species, being non-specific and capturing the widest range of taxa. Those methods are highly effective in herpetological surveys (Garden et al 2007; Sung et al. 2011). Garden et al. (2007) conducted their study in semi-arid environment of Australia, detecting with visual transects the greater number of species including some of them unique species only encountered by this method, as it occurred in our survey.

On the other hand, Stoning Transects method is a more specific method that detect less species and low number of individuals, but some of them elusive or fossorial difficult to detect by other methods, as showed in our results. It is a method that requires effort in flipping objects and usually researchers turn many rocks for detecting one or few individuals, as stated by Henderson et al. (2016). It was proven to be effective for fossorial snakes and lizards that use rocks and objects for hiding, thermoregulating by thigmothermy or foraging (Henderson et al. 2016).

Other specific method with low detections but important is the Pitfall Traps method. Few species and individuals were detected by this method, but some of them were elusive fossorial species (*Namibiana occidentalis* and *Rhinotyphlops lalandei,* see Appendix 1). Other studies have shown this lower detection compared with Visual Transects or visual encounters (Sung et al. 2011), but Pitfall Traps have been proven to be effective for small, cryptic, nocturnal and/or fossorial species, which are characteristic present in the species detected in our survey by this method. However, Pitfall Traps have limitations for detecting some taxa, for instance snakes (Gibbons & Semlistch 1981; Garden et al. 2007; Todd et al. 2007), as it occurred in our study that the only individual found was a juvenile, which could have more difficulties to escape from the bucket. In fact, in the present study, although several species of snakes were recorded, the detection of this group was very low, with few individuals recorded. This may be explained by the fact that funnel traps were not used with pitfall traps, which has proved to be an effective method in capturing this taxon in several studies, including arid areas as in the case of Thompson and Thompson (2007). Increasing the size of the buckets may be another possible solution for increasing the detection snakes and other groups. Pitfall traps were placed in sandy plain and riverbed microhabitats, and the species detected by this method could increase when extending to other microhabitats, but it could not be done in the current study due to the hard soil of the other microhabitats and equipment limitation.

In this way, Coverboards are other method of lower efficacy compared to other methods, null efficacy in our sampling, that could increase with some modifications. Other studies had also obtained a reduced output by this method (Sung et al. 2011), but it can has been effective for long-term herpetological studies (Ali et al. 2018), or in studies focused on species that inhabit the leaf litter as in North American forests (Moore 2005), showing that is a specific method. This technique has also obtained positive results in desert habitats (Rice et al. 1994), using artificial habitat arrays, which are exactly the same as Coverboards but raised above the ground with stone blocks in the corners, obtaining a better result when watering the soil under the coverboard. This suggests that the design used in our survey was not adequate, since white plywood sheets were used, a favourable colour for reptiles in times of higher temperature, which were not reached during the sampling period since it was in winter and early spring. In contrast, a dark colour or different material with greater heat retention may have been more effective during this time of year. Slight modifications in the design, such as those made by Rice et al. (1994), could increase the effectiveness of this method, or even just increase the period of the study could increase its detection rate.

One of the most specific methods that was inefficient in our survey was Fibroscope Transects method, although useful in other studies. Despite the proven usefulness and efficacy of the fibroscope detecting species that hide in crevices of arid areas (Parusnath et al. 2017) and that there are several species in the study area that hide and spend their periods of inactivity in crevices, under rocks or in burrows (Appendix 1), it had not been effective in the sampling despite we expected some effectiveness. The presence of these species in a sampling period such as late winter - early spring, in which this study was carried out, provides an empty methodological niche that can only be covered by a technique as the fibroscope. However, the lack of species or individuals detected is not due to the method itself, but to the device model used during sampling, which had a cable part with a larger than ideal diameter, as well as its high weight and bad manoeuvrability, which meant that it was not possible to reach the bottom of burrows and crevices that in the vast majority of cases do not have a straight shape, but rather multiple curves or nooks and crannies that could not be sampled properly with the device model used. This suggests that the analysis of this technique as inefficient is not real, and it would be necessary to use it in the field with other more advanced and lighter models that would allow the correct sampling of the shelters used by the reptiles.

Our results consider the effort done during the active methods and number of checks in passive methods, but there are also some human effort which was not considered. There are several studies that consider the effort or time spent in the transport until transects start, or in the preparation, assembly and revision of the traps, changing completely the efficiency by switching the effort definition (Rice et al. 1994), as others have also consider the economic costs of materials for traps or operational costs (Garden et al. 2007, Hutchens & DePerno 2009). This effort or costs were not considered in the current study, but in others as Sung et al. (2011), this consideration placed Pitfall Traps, previously considered less efficient method, as more efficient than Visual Transects regarding this researcher effort. Other methods are also inexpensive, mainly the passive methods as Coverboards, in which human effort is not required but this invested in checking, thus could be much more efficient when comparing in these terms.

Our survey was carried out in late winter - early spring and could deeply vary the results in another season. This study was focused in this period of the year when the herpetofaunal activity begins, and the results could be different when surveyed in warmer periods. The variation in the general effectiveness of the methods due to environmental factors was already demonstrated by Spence-Bailey et al. (2010), in their study carried out in a semi-arid zone, increasing the success of the methods used when daily temperatures increased, suggesting as optimal the last months of spring, with maximum temperatures above 25 - 30 °C and night temperatures above 15 °C, conditions that were not met during most of this sampling period. Spence-Bailey et al. (2010) also showed a variability produced by other environmental factors such as moon phase and rainfall in taxa sensitive to these factors such as geckoes and blind snakes (Appendix 1), also present in the study area of this research, although these factors were not evaluated due to reduced data for several species. The low abundance of individuals and large number of species with few records may have been caused or overestimated by the period in which the study was carried out, with greater inactivity on herpetofauna compared with warmer periods since they are ectothermic vertebrates. Thus, extending the period of the survey may increase the general effectiveness and detection of the methods, and this increase could be more marked in Pitfall Traps as more individuals foraging and active may be captured.

6. Conclusions

The results shown in the present study, carried out in a semiarid-arid gradient zone in southern Namibia, are similar to surveys conducted in other parts of the world regarding the effectiveness of different sampling methods. A complete methodological set is necessary to cover the different species and taxa of arid areas.

Visual transects and Free search methods were the most effective in terms of capture rates of individuals and species.

Other methods were more specific, being effective in detecting certain taxa. Pitfall traps were effective in detecting elusive and fossorial species such as *Namibiana occidentalis* or *Rhinotyphlops lalandei*.

The results of low or null effectiveness for certain methods as the use of Fibroscope or Coverboards, may suggest the modification of some techniques for these environments. However, an extension of the study to other season periods with higher herpetofaunal activity would be necessary to thoroughly evaluate the methods.

Further studies will be necessary to obtain an effective methodological set, with the widening of the methods evaluation in time and space, with the possibility of including recently used methodologies such as PIR cameras or fiber-optic borescopes, specifically developed for this kind of purpose.

Finally, the record of 31 species of reptiles and 2 species of amphibians in the area through this study, indicate an important species richness. The fact that the great majority have not undergone any assessment of their conservation status reflects the lack of data at a regional and global level for these increasingly threatened groups, urging more research on the topic.

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Appendices

List of the Appendices:

Appendix 1: Reptile species detected during the research[i]

- Family **Agamidae**

Western ground agama

Agama aculeata aculeata Merrem, 1820

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC

Distribution: Endemic to Southern Africa. Widely distributed: Angola, Namibia, Botswana, South Africa. Occupies Nama-Karoo, Succulent Karoo, Grassland, Albany thicket, Fynbos and Savanna biomes.

A. a. aculeata A. Andrés

Habitat and biology: This agama (76-117 mm SVL) is a diurnal and psammophilic species, that inhabits dry sandy areas with presence of shrubs, using burrows made by small mammals or rocks to hide. This species spends most of the day basking and foraging in a sit-and-wait strategy (Billawer & Heideman 1996). Males shift its colouration towards the breeding season, from cryptic colouration to some bright colours, having blueish head, although there is a wide colour variation among individuals.

Anchieta's agama

Agama anchietae Bocage, 1896

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Angola, Namibia, Botswana, Democratic Republic of the Congo, South Africa. Occupies Nama-Karoo, Succulent Karoo, Desert and Savanna biomes.

A. anchietae D. Hernández

Habitat and biology: This agama of around 80 mm SVL size (Buiswalelo et al. 2019) up to 140 mm. It is a diurnal, terrestrial and rupicolous species. It inhabits dry and plain sandy areas with sparse vegetation, but also low rock outcrops where it can easily hide between rocks. This species presents a variable but cryptic colouration, and sexual dimorphism by larger males with bigger heads, and bright colour during breeding season in the hot months.

Southern rock agama

Agama atra Daudin, 1802

Conservation status:

IUCN RedList: LC
Bates et al. 2014: LC

Distribution: Endemic to southern Africa. Namibia, Botswana, South Africa, Lesotho, and Swaziland. It inhabits a wide range of biomes, including Desert, Nama-Karoo, Grassland and Succulent Karoo.

A. atra F. Ceacero

Habitat and biology: This agama is a large (up to 140 mm SVL), highly rupicolous species, quite sociable that can form hierarchical groups of dominant male, other male, females and juveniles in the same territory (Bruton 1977). It inhabits rocky outcrops within a wide altitude range (sea level to 2200m). It shelters inside crevices or between rocks. This species presents a variable but cryptic colouration, and males turn into a bright breeding colouration with blue head.

- Family **Scincidae**

Namaqualand dwarf legless skink

Acontias tristis Werner, 1911

Conservation status:

IUCN RedList: LC
Bates et al. 2014: LC

Distribution: Occurs in South Africa and Namibia. Occupies Nama-Karoo, Succulent Karoo, and Desert biomes.

A. tristis. Image shared by Craig Van Rensburg

Habitat and biology: This legless skink has a size up to 150 mm SVL. It inhabits arid and semi-arid areas. The species is present in a wide range of altitude, from sea level to more than 1000 m. It is a psammophilous and fossorial species which is present in sandy soils, expending most of the lifetime beneath the sand. They are commonly found under rocks near sociable weaver nests.

Western three-striped skink

Trachylepis occidentalis (Peters, 1867)

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Namibia, Botswana, Angola, and South Africa. Occupies Nama-Karoo, Succulent Karoo, Desert, Savanna, Fynbos biomes.

T. occidentalis D. Hernández

Habitat and biology: It is a large species up to 115 mm SVL size. It inhabits arid areas, with scrub vegetation and karroid veld. The species is present from sea level to 900 m of altitude. It is a psammophilous species that hibernates during winter and has its breeding season during the early summer (Goldberg 2008). This species refuges in the bushes and tree clumps. It has a characteristic pattern of brown-orangish or orange back with three stripes, a vertebral stripe crossing its body and two more on the sides of the vertebral one.

Western rock skink

Trachylepis sulcata sulcata Peters, 1867

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to Namibia and South Africa. Occupies Nama-Karoo, Succulent Karoo, Desert, Savanna, Fynbos and Grassland biomes.

Female of *T. s. sulcata* D. Hernández

Habitat and biology: This skink has a size up to 85 mm SVL. It inhabits arid areas, with wide range of vegetation (from deserts to grassland and karroid veld) and altitude, being present from sea level to 1000 m. It is a rupicolous or petrophilous species which can be found in groups, mainly in rocky outcrops. This species has a marked sexual dimorphism, females and juveniles present a light-yellow colour with a dark brown or black striped pattern, whereas males usually present a uniform olive coloration, but have a high occurrence of melanistic individuals.

Variegated skink

Trachylepis variegata (Peters, 1870)

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to southern Africa: Angola, Namibia, South Africa. Occupies Nama-Karoo, Succulent Karoo, Desert, Savanna, Fynbos and Grassland biomes.

T. variegata D. Hernández

Habitat and biology: *T. variegata* is a small skink species up to 57 mm SVL size. It inhabits arid areas, being a mainly rupicolous species, occurring in rocky outcrops but also in sandy and gravel areas with rocks and bushes. It is also common around anthropic buildings as houses. It has brown or olive colouration with darker flanks and many dark spots on the back. Some individuals present orange colouration in the hind limbs and base of the tail.

- Family **Lacertidae**

Spotted desert lizard

Meroles suborbitalis (Peters, 1869)

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to southern Africa: Namibia and South Africa. Occupies Nama-Karoo, Succulent Karoo, Desert, Savanna and Fynbos biomes.

M. suborbitalis D. Hernández

Habitat and biology: Spotted desert lizard is a small lizard, up to 71 mm SVL size. It is present in arid areas, mainly desert and semi-desert habitats, inhabiting open sandy areas with sparse vegetation. It is a psammophilous and fast species that uses bushes but mainly old mammal burrows as refuge. Its colouration is variable, from light sand colour to darker orangish brown, with a dark spotted pattern and undefined pale stripes on the back.

Western sandveld lizard

Nucras tessellata (A. Smith, 1838)

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC

Distribution: Endemic to southern Africa: Namibia, Botswana, and South Africa. Occupies Nama-Karoo, Succulent Karoo, Savanna and Fynbos biomes.

N. tessellata. Image shared by Gabriel Martínez

Habitat and biology: This species is up to 94 mm SVL size with a remarkably long tail (up to 25 cm). It inhabits in arid areas, as dry riverbeds, karroid veld or some sandy areas, but mainly occurs in rocky outcrops and low mountains. It is a very quick species, being active during the morning and evening. Some population has a primarily scorpion-based diet, but it was demonstrated not to occur as general fact (Van der Meer et al. 2010). It has a characteristic colouration that intensifies in breeding season, with the anterior part of the body brown or black with many pale stripes, and a hind part of orange-reddish colour including the tail.

Plain sand lizard

Pedioplanis inornata (Roux, 1907)

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to southern Africa: Namibia and South Africa. Occupies Nama-Karoo, Succulent Karoo, Desert and Savanna biomes.

P. inornata D. Hernández

Habitat and biology: It is a small lacertid species, up to 62 mm SVL size with a long tail. It is present in arid areas, rarely in sandy habitats and normally in rocky outcrops, gravel soils, and low slopes of mountains. It is a very fast species that uses bushes and rocks as hideout. Its colouration is slightly variable, but mainly greyish on the anterior portion of the body and orangish on the hind portion, usually plain or with non-defined pale spots and stripes that can be more marked in some individuals. It has a typical movement with stops and movement of the anterior limbs in circles alternatively.

Spotted sand lizard

Pedioplanis lineoocellata
(Duméril & Bibron, 1839)

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to southern Africa: Namibia, Botswana, and South Africa. Occupies Nama-Karoo, Succulent Karoo, Desert and Savanna biomes.

P. lineoocellata D. Hernández

Habitat and biology: *Pedioplanis lineoocellata* is a small species, up to 65 mm SVL size with a long tail, similar to *P. inornata*. It is present in wide range of habitats, altitude, and vegetation cover, even in zones altered by agricultural activities. Although, it is usually found in rocky areas. Its colouration is variable, with an orange or orangish brown colouration with very variable ocellated pattern among subspecies, from few to many marked ocelli.

Namaqua sand lizard

Pedioplanis namaquensis
(Duméril & Bibron, 1839)

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to southern Africa: Namibia, Botswana, Angola, and South Africa. Occupies Nama-Karoo, Succulent Karoo, Desert, Grassland, Fynbos, Albany thicket and Savanna biomes.

P. namaquensis D. Hernández

Habitat and biology: *Pedioplanis namaquensis* is one of the smallest species of the genus, up to 55 mm SVL size. The presence of two different taxa within the species (Makokha et al. 2007) may separate Namibian and South African populations into subspecies. It occurs in open sandy areas and gravel areas with some bush cover. It digs burrows at the base of bushes. It has a brown colouration and orangish tail, with a characteristic pattern of thin pale longitudinal stripes, two dark bands on the flanks.

- Family **Cordylidae**

Attenborough’s flat lizard

Platysaurus attenboroughi
Whiting, Branch, Pepper & Keogh, 2015

Conservation status:

IUCN RedList: LC

Distribution: Namibia near endemic, present also in north South Africa. Occupies Nama-Karoo and Succulent Karoo biomes.

P. attenboroughi Image shared by Adrián Martín

Habitat and biology: This species of flat lizard has an average length of 72 mm SVL, and was recently discovered in 2015, being separated from *P. capensis* by DNA analysis (Whiting et al. 2015). It is a rupicolous species and occurs rocky habitats where it can hide in narrow crevices due to the dorso-ventrally flattened body. The species, as most *Platysaurus*, present marked sexual dimorphism, females and juveniles are dull brown cryptic coloration while the males during breeding season have bright striking colours, reddish-orange in the hind portion of the body and striking blue in the anterior portion, with blue anterior part of the forelimbs, belly and throat, which is UV-reflective as honest signal and contest settling between males. Males have also white spots and a vertebral stripe.

- Family **Gerrhosauridae**

Dwarf plated lizard

Cordylosaurus subtessellatus
(A. Smith, 1844)

Conservation status:

IUCN RedList: LC
Bates et al. 2014: LC

Distribution: Southern Africa endemic, Namibia, Angola, and South Africa. Occupies Nama-Karoo, Fynbos and Succulent Karoo biomes.

C. subtessellatus Image shared by Francois Theart

Habitat and biology: It is a small plated lizard with a 55 mm SVL length, cylindric and elongated body. It is present in arid zones, in sandy areas but mainly rocky outcrops with bushes or low slopes in mountains. Occurs from sea level up to 1200 m. It is a very fast species that shelters under stones and rocks. It has a characteristic colouration, a dark brown to black body with two longitudinal pale band from the snout to the tail, which is striking blue.

- Family **Gekkonidae**

Giant ground gecko

Chondrodactylus angulifer angulifer Peters, 1870

Conservation status:

IUCN RedList: LC
Bates et al. 2014: LC (Regional)

Distribution: Endemic to Southern Africa. Namibia, Botswana, South Africa. Occupies Nama-Karoo, Succulent Karoo, and Desert biomes.

Male of *C. a. angulifer* D. Hernández

Habitat and biology: This large gecko (max. 113 mm SVL) inhabits arid zones, occurring in gravel and sandy plains with sparse vegetation. It shelters in burrows and has nocturnal activity. The breeding season takes place in spring between September-January (Goldberg 2006). The colouration of the species is variable, from sandy-yellow and pale colours to intense orange. The pattern is also variable and can be used for individual identification. This species present sexual dimorphism since males have white ocelli on the back.

Bibron's gecko

Chondrodactylus bibronii (A. Smith, 1846)

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC

Distribution: Endemic to Southern Africa. Namibia, Botswana, South Africa. Occupies wide range of habitats including Nama-Karoo, Succulent Karoo, and Desert biomes.

C. bibronii D. Hernández

Habitat and biology: It is a nocturnal gecko of maximum 100 mm SVL. Inhabits arid zones, being present in rocky outcrops as it is a rupicolous gekkonid, and in anthropic buildings but not in urban areas. This species forms aggregations in shelters as crevices during the whole year (Meyer & Mouton 2007; Mouton 2011). Breeding season occurs in spring from November to January. The colouration ranges from pale grey to brownish, showing a marbled pattern of dark blotches and white spots, presenting various tubercles along the body.

Striped pygmy gecko

Goggia lineata (Gray, 1838)

Conservation status:

IUCN RedList: LC
Bates et al. 2014: LC

Distribution: Endemic to Southern Africa. Namibia and South Africa. Occupies Fynbos, Nama-Karoo, and Succulent Karoo biomes.

G. lineata D. Hernández

Habitat and biology: It is a pygmy nocturnal gecko with maximum size 31.8 mm SVL, being the smallest species of gecko in Southern Africa. Inhabits arid zones, being present in sandy plains with some vegetation cover, as it is the only mainly terrestrial species of the genus, although it is also present in rock outcrops. Is a nocturnal species that shelter in crevices, perennial herb stems, within the bark of dead vegetation as *Aloidendron dichotomum*. This species has a cryptic colouration of greyish tones with dark stripes pattern, more conspicuous in some individuals, and with presence of small orange spots. The tail varies its colouration from the same dull grey as the body to orange.

Bradfield's dwarf gecko

Lygodactylus bradfieldi Hewitt, 1932

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Namibia, Botswana, Angola, Zimbabwe, South Africa. Occupies Nama-Karoo, Succulent Karoo, Desert and Savanna biomes.

L. bradfieldi D. Hernández

Habitat and biology: This a small gecko (around 30 mm SVL) that occurs in arid areas. *L. bradfieldi* is a diurnal species that belong to the group of day dwarf geckoes. It is present in trees and shrubs since it is an arboreal species that mainly preys on ants. It shelters at loose bark and holes in the trees. It has an extremely cryptical colouration of dull grey with striped pattern that makes them hardly distinguishable from the bark of the trees that they inhabit.

Namaqua mountain gecko

Pachydactylus montanus Methuen & Hewitt, 1914

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC

Distribution: Endemic to Southern Africa. Namibia and South Africa. Occupies Nama-Karoo, Succulent Karoo, and Desert biomes.

P. montanus D. Hernández

Habitat and biology: *P. montanus* is a nocturnal species around 43 mm SVL size, that inhabits arid zones. Belongs to the *P. serval* complex that was recently revised (Bauer et al. 2006), solving some taxonomic issues, since many species of the complex are morphologically similar. This species occurs in rocky habitats, from rock outcrops and rocky plains to slopes and cliffs in a wide altitudinal range from sea level to 2225 m. Its colouration vary from juveniles with clear grey colour with dark and pale transversal bands to adults with pinkish or purplish-grey or brownish in some individuals, with a pattern of brown blotches, and white to yellow tubercles in the pale to yellowish tail.

Speckled gecko

Pachydactylus punctatus Peters, 1854

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Occurs in many countries of Southern and East-central Africa. Occupies Savanna, Nama-Karoo, Succulent Karoo, and Desert biomes.

Male *P. punctatus* D. Hernández

Habitat and biology: This nocturnal terrestrial gecko is a small species (up to 42 mm SVL) that inhabits semi-arid and arid areas but also grassy habitats. It is present from sea level to 1800 m. This species is not an exclusively rupicolous species as other from the genus and can be found in sandy plains and open areas or in more rocky outcrops. It shelters under rocks, within the vegetation or loose bark of dead trees. Its wide distribution and variable colouration may separate some Namibian populations into a different species. It usually has clear colour with dark or white-yellowish dots in the body, sometimes with brown spots pattern, but it can vary to more brownish colouration without dark blotches.

Common rough gecko

Pachydactylus rugosus A. Smith, 1849

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to Southern Africa. Namibia, Botswana, and South Africa. Occupies Savanna, Nama-Karoo, Succulent Karoo, and Desert biomes.

P. rugosus D. Hernández

Habitat and biology: This nocturnal terrestrial gecko has a size up to 65 mm SVL. It is mainly associated with river courses but also inhabits arid areas or anthropic modified areas. Occurs from sea level to 1500 m. It is not a decidedly rupicolous species and occurs in sandy soils, sheltering within shrub vegetation or bark of dead trees. This species was encompassed in a polytypic *P. rugosus* complex with another 2 species, but habitat preference, morphological, and DNA differences has split this complex into three different species (Lamb & Bauer 2000). This complex has a unique appearance with keeled and ridged dorsal tubercles. In *P. rugosus* the colouration is dark brown with non-well-defined banding and series of 5 light blotches from the nape to the tail, the first two often fused. Additionally, this species has spiny subcaudal scales that the other species from the complex lack.

Spotted barking gecko

Ptenopus garrulus maculatus Gray, 1866

Conservation status:

IUCN RedList: NE
Bates et al. 2014: LC

Distribution: Endemic to Southern Africa. Namibia, South Africa. Occupies Nama-Karoo, Succulent Karoo, Desert and Savanna biomes.

Male of *P. m. maculatus* D. Hernández

Habitat and biology: This small species of gecko (max. 60 mm SVL) inhabits dune and sandy areas, having burrowing behaviour with burrows slightly shallower than 40 cm deep of the common subspecies (Haacke 1975). It is a mainly crepuscular species; males call at the entrance of the burrows during sunset and early night, with breeding period from September to March (Hibbitts et al. 2007). This species present sexual dimorphism, subadult and adult males present a yellow patch on the throat.

- Family **Viperidae**

Horned adder

Bitis caudalis (A. Smith, 1839)

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to Southern Africa. Namibia, Angola, Zimbabwe, and South Africa. Occupies Savanna, Nama-Karoo, Succulent Karoo, and Desert biomes.

B. caudalis D. Hernández

Habitat and biology: This adder is around 40 cm size (max. 60 cm). It has mildly cytotoxic venom, and inhabits dry and sandy regions, being present mainly in sandy soil areas but also in rocky outcrops, ranging from 300-1600 m altitude. Shelters under rocks, vegetation or burying themselves in the loose sand, using this ambush technique for hunting, sometimes luring with the darkened tip of its tail. It preys mainly on lizards as gekkonids, skinks and lacertids, but also on birds, frogs, and small mammals. It can be active during day and night but mainly at dusk, reducing the activity slightly at 15° to drastically at 10° (DeNardo et al. 2002). It is viviparous, giving birth 3-8 hatchlings during summer. It has characteristic horns, although the colouration of this species is widely variable with light grey, olive brown, reddish and dark individuals, with a pattern of dark blotches through the body.

Desert mountain adder

Bitis xeropaga Haacke, 1975

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC

Distribution: Namibia near endemic. Namibia and South Africa. Occupies Nama-Karoo, Succulent Karoo, and Desert biomes.

B. xeropaga D. Hernández

Habitat and biology: *B. xeropaga* is a small adder of 30-40 cm (max. 60 cm) with mildly cytotoxic venom, that occurs in arid regions, in rocky hillsides and mountain slopes with scarce vegetation. Shelters under rocks. It is an elusive species with not much information about, the diet is almost unknown but should be the same as similar size adders that occur in Southern Africa. It is viviparous, with clutch size of 4-5 youngs born in late summer. The colouration of this adder is highly cryptic for granitic slopes, being grey and reddish-brown with a pattern of dark rectangular blotches with 2 yellow borders and 2 white spots flanking the other sides.

- Family **Elapidae**

Cape cobra

Naja nivea (Linnaeus, 1758)

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to Southern Africa. Namibia, Botswana, and South Africa. Occupies wide range of biomes including Nama-Karoo, Savanna and Succulent Karoo biomes.

N. nivea D. Hernández

Habitat and biology: This elapid averages 1.2-1.4 m up to 1.8 m. It inhabits arid regions up to 1600 m of altitude and uses old mammal burrows, crevices, old termitaria and anthropic buildings or debris as shelters. It is oviparous and has a highly neurotoxic venom, being one of the most venomous snakes of Africa. It is a diurnal snake that forages actively. Its diet is very wide, based on lizards, frogs, mammals, eggs, birds, and other snakes. It is known for being a frequent predator on sociable weaver nests (Covas et al. 2008), and it usually prey on other venomous species as *Bitis caudalis* or *B. arietans.* and other conspecifics, probably acting as intraguild predators (Layloo et al. 2017). The colouration of this cobra is extremely variable, from bright yellow and reddish to black and mottled individuals. Juveniles present a broad band on the ventral part of the neck.

- Family **Colubridae**

Beetz's tiger snake

Telescopus beetzii (Barbour, 1922)

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC

Distribution: Endemic to Southwestern Africa. Namibia and South Africa. Occupies Nama-Karoo and Succulent Karoo biomes.

T. beetzii Image shared by Gabriel Martínez

Habitat and biology: This colubrid has an average size of 40-60 cm (max. 68 cm). It inhabits arid parts of the Karoo, occurring in rocky outcrops where it can shelter in crevices and beneath rocks, or even old termite mounds. It is a nocturnal species that forages actively for lizards which are its main item prey (specially geckoes). *T. beetzii* is an oviparous species that lays eggs in summer. The colour is sandy-yellowish to orangish, with a pattern of numerous dark blotches in a row along the body.

- Family **Lamprophiidae**

Karoo sand snake

Psammophis notostictus Peters, 1867

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to Southern Africa. Namibia, Angola, and South Africa. Occupies wide range of biomes including Desert, Nama-Karoo, and Succulent Karoo.

P. notostictus D. Hernández

Habitat and biology: It is a long species averaging 75-90 cm up to 1 m long that inhabits arid scrubland and karroid vegetation habitats, occurring mainly in rocky areas but also in sandy soils, using stones and old termite mounds as shelters. It is a diurnal and quick-moving snake that forages actively for lizards and geckoes, but also rodents. It is venomous but harmless to humans. This species is oviparous and lays eggs in summer. The colouration is olive or brownish often with a vertebral line formed of pale spots and two more pale stripes on the sides.

Western sand snake

Psammophis trigrammus Günther, 1865

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC

Distribution: Endemic to Southwestern Africa. Namibia, Angola, and South Africa. Occupies Desert, Savanna Nama-Karoo, and Succulent Karoo biomes.

P. trigrammus G. Franco

Habitat and biology: This long snake averages 90 cm up to 1.2 m long, and inhabits arid scrubland, savanna and deserts occurring in rocky outcrops, low slopes and in sandy soils, sheltering in bushes or between rocks. It is a diurnal and quick-moving snake that forages actively for lizards. It is venomous but harmless to humans. It is an oviparous species. The colouration is olive or greyish brown often with a dark vertebral line flanked by two light bands.

Southwestern shovel-snout

Prosymna frontalis (Peters, 1867)

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC

Distribution: Endemic to Southern Africa. Namibia, Angola, and South Africa. Occupies Desert, Nama-Karoo, and Succulent Karoo biomes.

P. frontalis D. Hernández

Habitat and biology: This species averages 30-35 cm up to 44 cm length and inhabits rocky habitats in arid areas with karroid shrub. It is nocturnal oviparous species, that forages at night mainly preying on reptile eggs. It is brown or olive often pale greyish, with dark edged scales that form a mosaic pattern. It has a characteristic dark collar behind the head, followed by smaller blotches.

- Family **Leptotyphlopidae**

Western thread snake

Namibiana occidentalis (FitzSimons, 1962)

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC

Distribution: Endemic to Southern Africa. Namibia and South Africa. Occupies Desert, Nama-Karoo, and Succulent Karoo biomes.

N. occidentalis D. Hernández

Habitat and biology: This small blind snake (17-20 cm, max. 32 cm) was previously included in *Leptotyphlops* genus, but molecular studies (Adalsteinsson et al. 2009) restructured Leptotyphlopidae family, including this species into the new genus *Namibiana*. It inhabits arid regions and it is fossorial, being active during the night. Its diet is based on termites. It shelters under rocks or logs. The colour is variable among individuals from greyish brown to purplish.

- Family **Typhlopidae**

Delalande's beaked blind snake

Rhinotyphlops lalandei
(Schlegel, 1839)

Conservation status:
IUCN RedList: NE
Bates et al. 2014: LC (Regional)

Distribution: Endemic to Southern Africa. Widely distributed. Occupies Fynbos, Albany Thicket, Savanna, Grassland, Nama-Karoo, and Succulent Karoo.

R. lalandei D. Hernández

Habitat and biology: This blind snake averages 25-30 cm length, inhabits a wide range of habitats from savanna to arid or semi-arid. It is a burrowing species being active during the night when it can be found outside, especially after rains. It shelters under rocks or logs, and feeds predominantly on termites. It is oviparous. The colouration is variable being pinkish or flesh colour while adults are greyish brown or dark. The scales of the snout have been modified to a hard beak that they use to dig on firm soils. It has also modified scales on the tip of the tail to form a spike present also in other species of the genus, that they use as defence.

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[i] Sources: Meiri (2008); Marais (2011); Alexander and Marais (2013); Bates et al. (2014); The IUCN Red List of Threatened Species (2020).

Conservation status in Bates et al. 2014 was assessed by SARCA (Southern African Reptile Conservation Assessment) following IUCN criteria until year 2009.

Regional Conservation status does not include Namibia (it was assessed for South Africa, Lesotho, and Swaziland).