Herpetological Conservation and Biology 17(1):145–154.
Submitted: 6 March 2021; Accepted: 11 February 2022; Published: 30 April 2022.

# Extensions to the Known Geographic Distributions of Reptiles in the Great Karoo, South Africa

***Nicolas S. Telford[1,8], Graham J. Alexander[2], Francois S. Becker[1,7], Werner Conradie[3,6], Adriaan Jordaan[4], Luke Kemp[5], Anja le Grange[1], Alexander D. Rebelo[3], Paula Strauss[1], Jody M. Taft[1], Joshua Weeber[1], and Krystal A. Tolley[1,2]***

*[1]South African National Biodiversity Institute, Kirstenbosch Research Centre, Private Bag X7, Claremont 7735, Cape Town, South Africa*
*[2]School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Private Bag 3, Wits 2050, Johannesburg, South Africa*
*[3]Port Elizabeth Museum, Post Office Box 11347, Humewood 6013, Qeberha, South Africa*
*[4]Department of Zoology and Entomology, University of the Free State, 205 Nelson Mandela Drive, Park West 9301, Bloemfontein, South Africa*
*[5]African Snakebite Institute, 814 Wapadrand Road, 0050, Pretoria, South Africa*
*[6]Department of Nature Conservation Management, Natural Resource Science and Management Cluster, Faculty of Science, George Campus, Nelson Mandela University, Private Bag X 6531, George 6530, South Africa*
*[7]National Museum of Namibia, Post Office Box 147, Windhoek, Namibia*
*[8]Corresponding author, e-mail: n.telford@sanbi.org.za*

*Abstract*.—**The Great Karoo is an ecologically fragile, poorly studied arid region in central South Africa. With the discovery of shale gas as a potential resource in the Great Karoo, it is expected that a substantial footprint will be left in this region if gas extraction proceeds. This highlights the need for biodiversity surveys of the Great Karoo of taxonomic groups, including reptiles, to collect baseline distribution data from across the proposed shale gas extraction area to inform impact assessments. Over the course of 3 y, we conducted reptile surveys at 36 targeted sites and collected data in the form of voucher specimens, observations, photographs and/or DNA samples. During these surveys, we collected records from nine of the species we found that lead to adjustments to their distribution maps. Despite South Africa being the most comprehensively sampled country in Africa for reptiles, our findings highlight the insufficiencies in baseline distribution data for reptiles and the need for comprehensive biodiversity sampling.**

*Key Words*.—Africa; biodiversity data; Gekkonidae; Gerrhosauridae; Scincidae

## Introduction

South Africa is well-sampled for reptiles relative to other countries in Africa (Tolley et al. 2016). Despite this, there are several regions within South Africa that stand out as data poor, particularly the arid central regions of the country such as the Great Karoo, including the southern extent of the Great Escarpment. Furthermore, most records come from easily accessible regions around towns, in protected areas (Branch and Braack 1989; Conradie et al. 2016), and close to arterial roads (Botts et al. 2011), leaving less accessible areas largely unsampled. Reptile species richness in the Great Karoo appears to be low compared to other parts of South Africa (see Branch 2014a) but given that the Great Karoo is a poorly sampled region (Fig. 1), the low measures of richness may be biased due to poor sampling (see Farooq et al. 2021).

The Great Karoo is characterized by a high plateau (averaging about 1,200 m elevation), punctuated by large inselbergs (i.e., an isolated hill rising abruptly from relatively flat surroundings) and more continuous mountainous areas reaching up to about 2,000 m elevation (Fig. 2). The plateau is broken in the south by the Great Escarpment, below which the landscape drops in elevation (to approximately 500–900 m). The region is generally arid to semi-desert with 70–500 mm annual rainfall, which usually falls as short, intense bouts (Mucina et al. 2006). The range of temperatures is extreme, varying from -5° C in winter to 43° C in summer (Mucina et al. 2006). There are few perennial rivers, and the vegetation mainly consists of a sparse covering of short, arid-adapted shrubs and succulents with pockets of fynbos (i.e., sclerophyllous heathland vegetation occurring only in South Africa) and grassland at the higher elevations (Mucina et al. 2006). The arid conditions have resulted in an ecologically

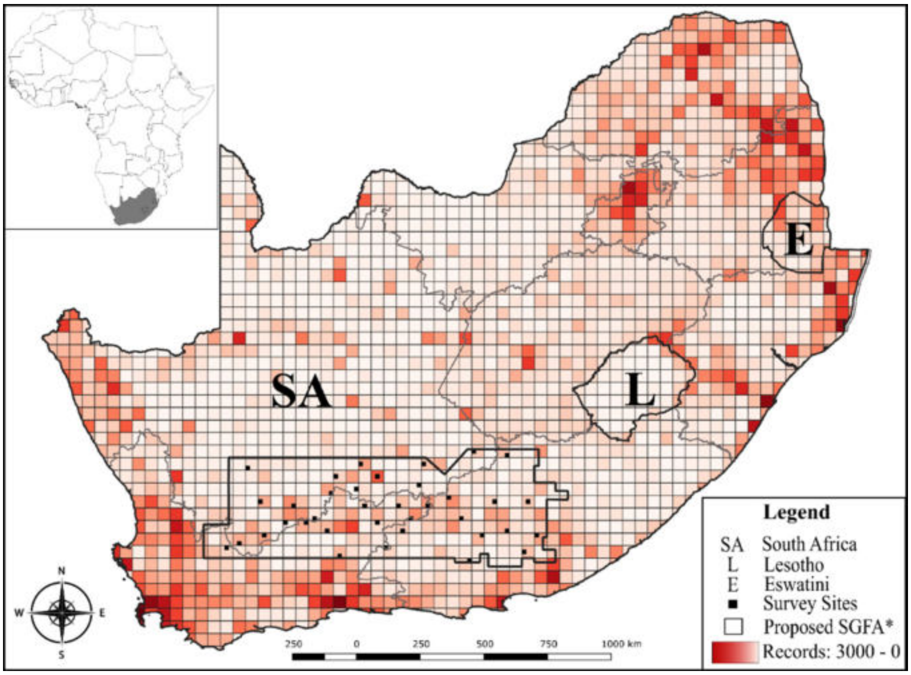


**Figure 1.** Density of reptile records ranging from 0 (lightest) to 3,000 (darkest) at quarter degree square resolution for South Africa, Lesotho, and Eswatini. The proposed shale gas fracturing area across the Great Karoo is bounded by the polygon and the 36 survey sites (pentads) are indicated as small black squares. Country boundaries shown in heavy black outlines and provincial boundaries in light grey outlines. In the legend, SGFA = Shale Gas Fracturing Area.

fragile habitat with the impacts of land degradation forming long-lasting changes to the landscape and long recovery times for the reestablishment of natural habitat (Milton and Hoffman 1994; Conradie et al. 2016).

The deep underlying stratigraphy of the Great Karoo is composed of thick sedimentary rock deposits of marine sediments and glacial tillites formed about 300–400 Mya, followed by marine sedimentation deposited in a large inland sea environment approximately 180–300 Mya (McCarthy and Rubridge 2005). The 3,000 m thick sedimentary deposits are rich in shales, many of which contain methane gas, mainly at depths of around 2,000 m (Scholes et al. 2016). The presence of shale gas in the Great Karoo prompted several energy companies to apply for gas exploration rights, potentially leading to full-scale gas extraction operations using hydraulic fracturing (i.e., fracking; de Wit 2011; Scholes et al. 2016). Hydraulic fracturing and the associated development of infrastructure have been shown to notably impact biodiversity directly through the input or output of air, water, solid and liquid waste disposals, and the complex chemicals used in fracking fluid and indirectly through habitat degradation and fragmentation associated with such mining developments (e.g., Gillen and Kiviat 2012; Kiviat 2013; Annevelink et al. 2016; Meng 2017). These impacts would pose significant risks across the Great Karoo landscape and to the biodiversity of the region (Todd et al. 2016).

Prior to the issuing of licenses for exploration, the South African Department of Forestry, Fisheries and the Environment commissioned a Strategic Environmental Assessment (SEA), which was informed by existing biodiversity data (Scholes et al. 2016). During the inception of the report, it became clear that the existing biodiversity dataset for the Great Karoo was wholly inadequate for the development of a sound, environmentally sustainable development plan (Holness et al. 2016). This provided the impetus for additional biodiversity surveys to be conducted across the Great Karoo to improve knowledge for land use decision-making.

A large, collaborative biodiversity survey project was established to gather data on 11 broad taxonomic groups (e.g., amphibians, bees, butterflies, dragonflies, fishes, grasshoppers, mammals, plants, reptiles, scorpions, and spiders; Lee et al. 2018; Woodgate et al. 2018; Edge and Mecenero 2019; Petersen et al. 2020) at selected sites across the 140,000 km$^2$ shale gas footprint. Sites were chosen during the collaborative project planning phase to maximize the range of habitats sampled for all taxonomic groups, and to guide survey effort toward poorly sampled areas to maximize the value of new records. The project planning team identified 50 potential sites during the planning phase and 30 of these were considered compulsory to survey for all taxonomic groups whereas the

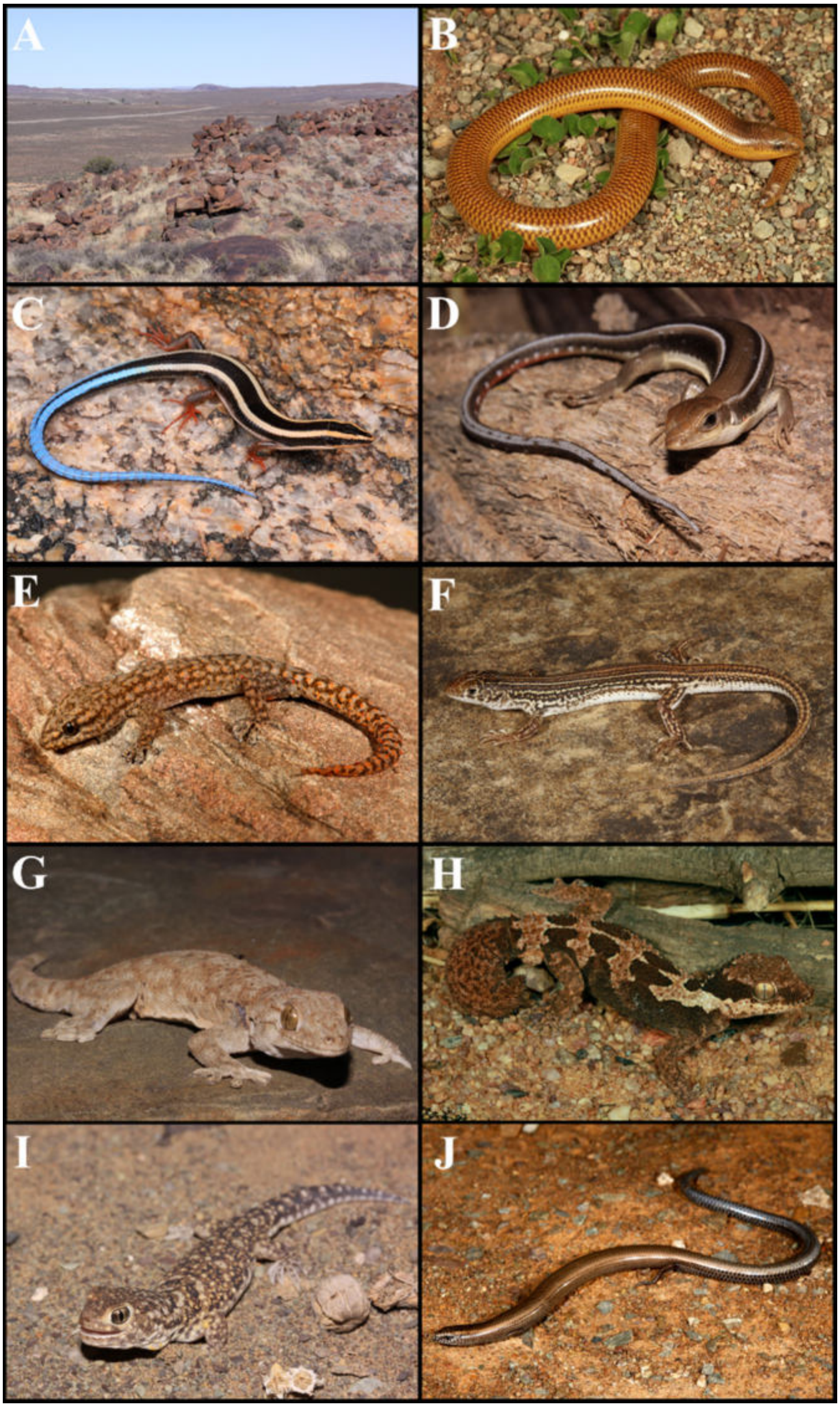


**FIGURE 2.** Typical Great Karoo habitat (A) and examples of species with extensions to their known geographic distributions in the proposed Great Karoo shale gas fracking area. (B) Western Legless Skink (*Acontias occidentalis*), (C) Dwarf Plated Lizard (*Cordylosaurus subtesselatus*), (D) Namaqua Plated Lizard (*Gerrhosaurus typicus*), (E) Braack's Dwarf Leaf-toed Gecko (*Goggia braacki*), (F) Holub's Sandveld Lizard (*Nucras holubi*), (G) Thin-skinned Gecko (*Pachydactylus kladaroderma*), (H) Common Rough Gecko (*Pachydactylus rugosus*), (I) Common Barking Gecko (*Ptenopus garrulus*), (J) Cape Dwarf Burrowing Skink (*Scelotes caffer*). (Photographed by Nicolas S. Telford [A, D, G, I], Luke Kemp [B, C, H], and Werner Conradie [E, F, J]).

remaining 20 were intended to be surveyed if feasible.

Prior to the targeted surveys, approximately 4,782 reptile occurrences had been recorded from the shale gas fracking area of the Great Karoo, representing 113 of the approximately 128 species that could possibly be expected there (Holness et al. 2016; Supplemental Information Table S1). Because much of the area was poorly surveyed (Fig. 1), we expected that the geographic distribution of some species might be more widespread in the Great Karoo than previously mapped (see Bates et al. 2014). Therefore, we collated all new reptile records gathered during surveys of the shale gas fracking area and compared these to the known and interpreted distributions (Bates et al. 2014; International Union for the Conservation of Nature [IUCN] 2021) to highlight instances where new records extended the current interpreted geographic ranges of species leading to adjustments to the existing range maps.

## Materials and Methods

Sample sites were selected as 8 × 8 $km^2$ pentads (McKay et al. 1979; Petersen et al. 2020) while ensuring coverage of the primary environmental gradients (specifically rainfall, normalized difference vegetation index, elevation, and temperature). For reptiles, we surveyed 36 of the possible 50 identified pentads. We recorded reptiles during active searches in the pentads between March 2016 and April 2018. Active searches during the day consisted of targeted searches or transects where we located reptiles visually while walking, rock flipping, and searching in rock cracks. A team of three to four experienced herpetologists surveyed each pentad over three consecutive days. We captured reptiles by hand using a variety of tools including nooses, large forceps, snake hooks, and snake tongs. At night, we conducted active searches by road cruising on tar or dirt roads at approximately 30–40 kph for up to 2 h or until the ambient temperature dropped below 20° C. We captured animals by hand, photographed them, and took voucher specimens and/or DNA samples. Latitude and longitude were logged using a Garmin 64x or Garmin eTrex Vista (Garmin International Incorporated, Olathe, Kansas, USA) handheld GPS (± 3 m precision; projection: WGS84). We used field guides and primary literature to identify captured animals and we deposited voucher specimens in the herpetology collection of the Port Elizabeth Museum (PEM).

***Reassessment of distributions***.—We plotted all new records using QGIS v2.18.24 (http://qgis.osgeo.org) and overlaid these with their interpreted distributions (IUCN 2021). The overlay of new points and existing distribution maps were inspected for points that fell outside of the interpreted distributions, and these were considered extensions of the known range. In addition, we viewed iNaturalist for additional records given that members of the public had been encouraged to upload observations to that platform under an initiative set up for the larger project that covered all taxon groups (https://www.inaturalist.org/projects/karoo-biogaps). We include only research grade records and these records were also verified by GJA, WC, KAT, and JW.

***Phylogenetic identification of an unidentified gecko***.—While searching in the pentad located at -31°49’12”S, 18°46’48”E (1,455 m elevation), we found a small gecko under a rock, but it shed its tail by autotomy and escaped before identification could be made. We extracted DNA from the autotomized tail and DNA sequenced three genes (two mitochondrial and one nuclear). We analyzed these data within a phylogenetic framework together with an existing phylogenetic dataset (Heinicke et al. 2017), allowing us to identify the individual (Supplemental Information provides details of this analysis).

## Results

We collected 2,053 new reptile occurrence records representing 95 species during the surveys, increasing the dataset of occurrence records for this region by 43%. These new records were from 16 families and 53 genera (312 records were for snakes, 3,429 for lizards, 397 for tortoises and 31 for terrapins). Our phylogenetic analysis confirmed the identity of the unidentified gecko as Braack’s Dwarf Leaf-toed Gecko, *Goggia braacki* (Fig. 2; results provided in Supplemental Information). Holub’s Sandveld Lizard (*Nucras holubi*; Fig. 2) had never previously been recorded from the Great Karoo fracking area (Supplemental Information Table S1).

Notably, our new survey records (Fig. 3) resulted in substantial increases in the area of the known geographic ranges of six species: the Western Legless Skink (*Acontias occidentalis*; Fig. 2); Dwarf Plated Lizard (*Cordylosaurus subtessellatus*; Fig. 2); Namaqua Plated Lizard (*Gerrhosaurus typicus*; Fig. 2); *Goggia braacki*; Thin-skinned Gecko (*Pachydactylus kladaroderma*; Fig. 2) and Cape Dwarf Burrowing Skink (*Scelotes caffer*; Fig. 2 and 4, Table 1, Supplemental Information Table S2). Our surveys further resulted in smaller adjustments of the range maps for *Nucras holubi,* Common Rough Gecko (*Pachydactylus rugosus*; Fig. 2) and Common Barking Gecko (*Ptenopus garrulus*; Fig. 2 and 4, Table 1, Supplemental Information Table S2). The new record of *P. rugosus* is noteworthy because it provides confirmation of the southern extent of the range. Previously, this species had only been recorded once in

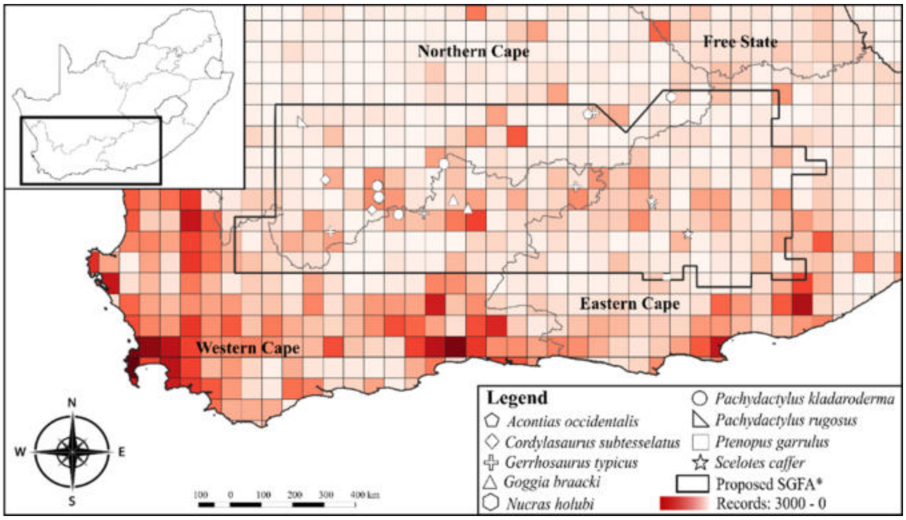


**Figure 3.** Localities of records collected within the proposed Great Karoo shale gas fracking area of Western Legless Skink (*Acontias occidentalis*), Dwarf Plated Lizard (*Cordylosaurus subtessellatus*), Namaqua Plated Lizard (*Gerrhosaurus typicus*), Braack's Dwarf Leaf-toed Gecko (*Goggia braacki*), Holub's Sandveld Lizard (*Nucras holubi*), Thin-skinned Gecko (*Pachydactylus kladaroderma*), Common Rough Gecko (*Pachydactylus rugosus*), Common Barking Gecko (*Ptenopus garrulus*) and Cape Dwarf Burrowing Skink (*Scelotes caffer*). In the legend, SGFA = Shale Gas Fracturing Area.

this area, from approximately 120 km south of all other records. New records from our surveys for two of these species (*Ptenopus garrulus*, *Acontias occidentalis*) were recently recorded in the literature (Rebelo et al. 2018a,b) but are included here for completeness of mapping and reporting. The IUCN conservation status of all species reported on here is Least Concern (IUCN 2021). Increases in measures of area for the known geographic ranges within South Africa varied from 1–49% (Table 1). Our surveys and additional data increased the interpreted distributions of *Acontias occidentalis* by 13% and extended the species range south by 200 km; *Cordylosaurus subtessellatus* by 22% and filling a gap in the previously disjunct distribution; *Gerrhosaurus typicus* by 44%; *Goggia braacki* by 49%; *Nucras holubi* by 2%; *Pachydactylus kladaroderma* by 17%; *Ptenopus garrulus* by 1%; and *Scelotes caffer* by 9% (Figs. 3 and 4, Table 1).

## Discussion

The results from these surveys provide a significant contribution to our knowledge on Great Karoo herpetological diversity and distributions. In addition to increasing the occurrence dataset for reptiles in the Great Karoo by 43%, our extensive surveys have improved knowledge on the range for nine reptile species and allowed for the reinterpretation of several distribution maps. Here, we report on the extensions and adjustments to the known ranges for these nine species: *Acontias occidentalis* is a fossorial species that occurs across central southern Africa, into southern Angola (Broadley and Greer 1969). In South Africa, the species occurs from northern Limpopo Province extending west into the Northern Cape Province. Recent phylogenetic analyses have shown that records from the Northern

**Table 1.** Original and updated measures of distribution size (km$^2$) for the South African portion of the distributions of reptile species found in the Great Karoo. The change in distribution size indicated as the percentage (%) increase. For endemicity, E = endemic and NE = non-endemic.

| Common Name | Species | Family | Endemicity | Original distribution | New distribution | % increase distribution |
|---|---|---|---|---|---|---|
| Western Legless Skink | *Acontias occidentalis* | Scincidae | NE | 157,807 | 178,363 | 13.0 |
| Dwarf Plated Lizard | *Cordylosaurus subtessellatus* | Gerrhosauridae | NE | 76,083 | 92,607 | 21.7 |
| Namaqua Plated Lizard | *Gerrhosaurus typicus* | Gerrhosauridae | E | 87,238 | 125,201 | 43.5 |
| Braack's Dwarf Leaf-toed Gecko | *Goggia braacki* | Gekkonidae | E | 968 | 1,445 | 49.3 |
| Holub's Sandveld Lizard | *Nucras holubi* | Lacertidae | NE | 356,660 | 362,823 | 1.70 |
| Thin-skinned Gecko | *Pachydactylus kladaroderma* | Gekkonidae | E | 25,916 | 30,428 | 17.4 |
| Common Barking Gecko | *Ptenopus garrulus* | Gekkonidae | NE | 392,145 | 397,319 | 1.30 |
| Cape Dwarf Burrowing Skink | *Scletotes caffer* | Scincidae | E | 108,119 | 117,423 | 8.60 |

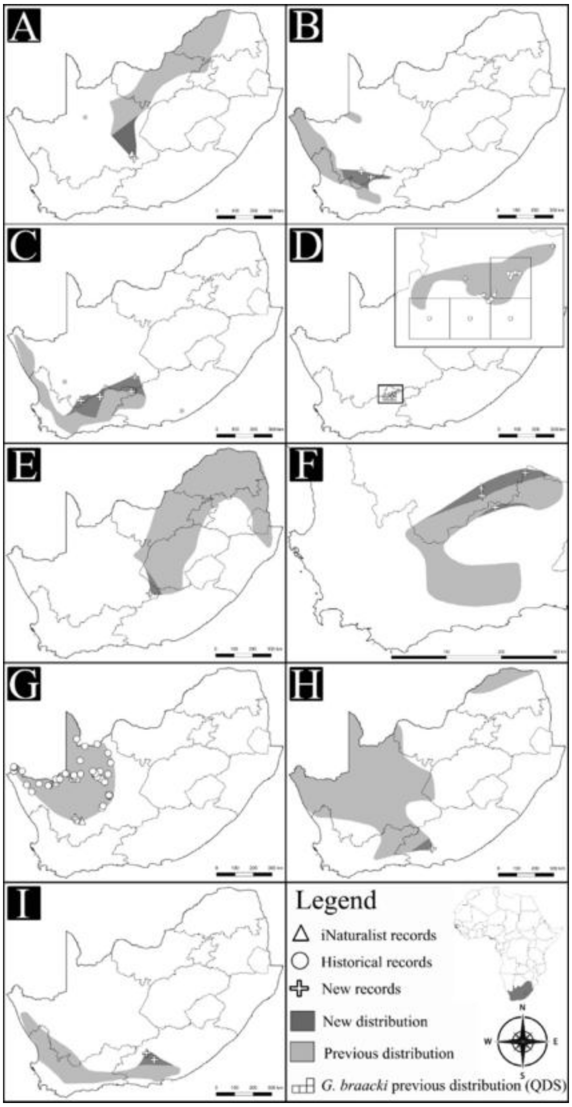


**Figure 4.** Previous range maps from International Union for the Conservation of Nature (light shading) and area increases (dark shading) refined according to new records (white crosses) for (A) Western Legless Skink (*Acontias occidentalis*), (B) Dwarf Plated Lizard (*Cordylosaurus subtesselatus*), (C) Namaqua Plated Lizard (*Gerrhosaurus typicus*), (D) Braack's Dwarf Leaf-toed Gecko (*Goggia braacki*) (with inset), (E) Holub's Sandveld Lizard (*Nucras holubi*), (F) Thin-skinned Gecko (*Pachydactylus kladaroderma*) (zoomed in), (G) Common Rough Gecko (*Pachydactylus rugosus*), (H) Common Barking Gecko (*Ptenopus garrulus*) and (I) Cape Dwarf Burrowing Skink (*Scelotes caffer*). Previous range map for *Goggia braacki* shown as the low-resolution grid cells where the species had been recorded.

Cape and western North West provinces (Bauer 2014a) previously assigned to Thin-tailed Legless Skink (*Acontias gracilicauda*) should be assigned to the *A. occidentalis* species complex (Busschau et al. 2017). The reassignment of these historical records, an iNaturalist record (no. 5374244) and the new museum-backed records extended the range south by 200 km.

*Cordylosaurus subtessellatus* occurs in the arid western parts of southern Africa, from south-western Angola through western Namibia (excluding true desert) to western South Africa (Visser 1984; Branch 1998; O'Connor et al. 2006). In South Africa, it occurs mainly in the west from the Namibian border to the central Cape Fold Mountains. Isolated records have been recorded from the Karoo National Park in the east along the Great Escarpment (Branch and Braack 1989). The new records from our surveys filled the gap between the main western distribution and the isolated Great Karoo records.

*Gerrhosaurus typicus* is distributed along the arid western and southern margins of the country. It possibly extends into southern Namibia (Griffin 2003) but has not yet been recorded from there. Although there are few records from the Great Karoo and the Eastern Cape Province (Bates 2014) it is expected to occur more widely. Our new records extend the range northwards and westward along the Great Escarpment.

*Goggia braacki* is endemic to the Great Karoo and is restricted to a narrow belt of dolerite rock formations and montane grassland along the summit ridge of the Nuweveldberg Mountains (Good et al. 1996; Branch 1998). This new record contributed substantially to the extension of the known range (northernmost point) and refinement of its range map. An additional record of this species from the upper western Karoo National Park (PEM R23605, which is also logged on iNaturalist: no. 9880111), was also included for re-evaluation of the distribution. Previously, the interpreted distribution for this species was greatly influenced by the conversion of the few original historical point locality records to quarter degree grid cells during the South African Reptile Conservation Atlas project (Bates et al. 2014). These points were then subsequently transformed to grid cell centroid points and plotted at this lower resolution (see Branch 2014b) instead of using the original point locality information. The result was that the distribution was erroneously shown to extend far to the south (Branch 2014b), well outside of the mesic mountainous habitat where this gecko occurs. We therefore refined this map by including the two new records (this study and the PEM/iNaturalist record), but also re-mapping the original records with accurate coordinates to produce an estimate of its distribution at the appropriate resolution. This approach has provided sufficient information to create a significantly revised and more realistic interpretation of the distribution.

*Nucras holubi* is widespread in the eastern, mesic areas of southern Africa, extending into Eswatini and central South Africa (Burger 2014). This lizard has not been previously recorded from the Great Karoo fracking region, and our record extends the known range by approximately 80 km to the southwest. The endemic *Pachydactylus kladaroderma* occurs in the Western

Cape Fold Mountains and western extent of the Great Escarpment, into the Great Karoo (Bauer 2014b). The new records slightly increase the known distribution northwards in the Great Karoo. *Pachydactylus rugosus* occurs in parts of Namibia, Botswana, and Angola with the southernmost record in the Northern Cape Province in South Africa (Bauer 2014c). The southern extent of the distribution was based on a single specimen collected by W.R. Branch in 1983 from west of Williston (PEM R4773) which is approximately 250 km distant from the nearest record to the northeast (see Bauer 2014c). We also recorded this species proximate to the existing historical record and with an additional iNaturalist record (no. 54045446). Thus, we confirm the southern extent of the range to be around the town of Williston in the northwestern parts of the Great Karoo.

Two subspecies of *Ptenopus garrulus* are currently recognized (i.e., *P. g. garrulus* and *P. g. maculatus*). Our newly collected material was assigned to the latter subspecies based on dorsal color patterns (Haacke 1975; Branch 1998). This subspecies occurs across most of the arid western regions in southern Africa. In South Africa, it occurs across most of the arid central and northwestern regions (Branch 2014). These new records from our Great Karoo surveys have recently been published (Rebelo *et al*. 2018a) and have extended the range eastward by 80 km.

The endemic *Scelotes caffer* occurs across southwestern South Africa from the Eastern Cape Province westward and north along the coastal margin of the west coast of South Africa. Although previously thought to occur as disjunct subpopulations (Branch 1990; Branch and Bauer 1995), improved sampling from our surveys suggests that the range is continuous (Rebelo et al. 2018b). These records extend the range 60 km northwards in the Eastern Cape Province.

Improvements in data quantity and quality for distribution records were clearly valuable for improving the credibility of interpreted distribution of these species. This will allow for better quality assessments of extinction risk through the IUCN Red List assessment process (IUCN 2012). Furthermore, the collation of these data across various taxonomic groups is an important contribution to land use decision-making through the identification of priority habitats that may be sensitive to proposed future land use changes, such as shale gas fracking. Thus, there is a direct progression of information flow from survey data to conservation planning and decision making (Holness et al. 2016).

***Conclusion***.—The substantial extensions to the interpreted geographic distributions of species recorded during our surveys provide a clear example as to why it is vital for biodiversity surveys to target regions where there are few existing records. In South Africa, reptile distribution data are clustered around major human settlements, protected areas and accessible areas, resulting in bias in species richness maps (e.g., Branch 2014a, see Botts et al. 2011). Future surveys should target regions that are poorly sampled to allow unbiased assessment of reptile species richness, diversity and distributions (Conradie et al. 2016, 2020; Tolley et al. 2016, 2020; Venter and Conradie 2015). Other poorly sampled parts of South Africa include the arid north and central regions such as the Northern Cape and North West provinces (see Branch 2014a) and these areas would benefit from targeted baseline surveys. Furthermore, most other regions of Africa are inadequately sampled (Farooq et al. 2021), even in comparison to poorly sampled areas of South Africa (see Tolley et al. 2016). Given the significant impact that targeted surveys still have in the comparatively well-sampled South Africa, our findings highlight the need for comprehensive biodiversity sampling across Africa.

*Acknowledgments*.— This work was carried out with funding from the National Research Foundation of South Africa (NRF Rated Research Incentive Funding: UID 85413 and Foundational Biodiversity Information Program: UID 98864), and logistical support from the South African National Biodiversity Institute and the Port Elizabeth Museum. We are extremely grateful to all the Karoo landowners for access to their properties and their remarkable hospitality and assistance. Thanks to Darren Pietersen and Marius Burger for assistance with the mapping. Research permits were issued by the Eastern Cape (CRO35/15CR, CRO36/15CR, CRO67/16CR, CRO68/16CR, 185/16CR, CRO 186/16CR), Northern Cape (OBD3157-FAUNA195/2014, OBD0458-FAUNA0278/2016 and FAUNA0279/2016) and Western Cape (0056-AAA008-00047, CN44-59-5795) provinces.

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Supplemental Information: http://www.herpconbio.org/Volume_17/Issue_1/Telford_etal_2022_Suppl.

**Nicolas S. Telford** is the Laboratory Manager at the Leslie Hill Molecular Ecology Laboratory at the South African National Biodiversity Institute in Cape Town. His research interests include amphibian and reptile conservation, molecular systematics, and biogeography of African herpetofauna. (Photographed by David Botha).

**Graham J. Alexander** is a Professor at the University of the Witwatersrand, South Africa, and heads the Alexander Herps Lab. His research interests are focused on the interface between herpetology, biogeography, ecology, physiology, and conservation. (Photographed by Bryan Maritz).

**Werner Conradie** holds a Master's in Environmental Science and has 15 years of experience in southern African herpetofauna, with his main research interests focusing on the taxonomy, conservation, and ecology of amphibians and reptiles. Werner has undertaken research expeditions to most southern African countries and is currently the Curator of Herpetology at the Port Elizabeth Museum (Bayworld), South Africa. (Photographed by Kostadin Luchansky).

**Krystal A. Tolley** is a Principal Researcher at the South African National Biodiversity Institute in Cape Town. Her interests are phylogenetics, biogeography, and conservation of reptiles, and she serves on several International Union for the Conservation of Nature Specialist Groups. (Photographed by Luke Verburgt).