Distribution of Temminck's pangolin (*Smutsia temminckii*) in South Africa, with evaluation of questionable historical and contemporary occurrence records

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ABSTRACT

Temminck's pangolin (*Smutsia temminckii*) is a threatened mammal found in southern and eastern Africa. It is the most widely distributed African pangolin species yet is listed as Vulnerable on the IUCN Red List due to a projected population decline of 30%–40% within the next three generations. This species' secretive, predominantly nocturnal behaviour and generally low population densities make it difficult to directly assess its distribution, and thus, alternative methods are required. Furthermore, many historical and some contemporary records of this species exist from outside of its accepted range, suggesting that the distribution may be greater than currently accepted, although the validity of these records has never been assessed. We used MaxEnt modelling to evaluate the most likely distribution of *S. temminckii* in South Africa and compared the past and present distribution of the species, as well as assessed the probable validity of the questionable records. Our results suggest that one of the questionable historical museum records is probably valid, while the other may refer to an erroneous collecting locality. At least some contemporary sightings which were originally deemed questionable are probably valid, while others should be treated as dubious until supporting information to validate their authenticity becomes available.

Keywords: conservation, environmental niche modelling, *Manis temminckii*, MaxEnt

1 INTRODUCTION

A good understanding of a species' distribution is vital for assessing its conservation status and identifying suitable areas where the species can survive (Guisan & Thuiller, 2005; Mota-Vargas & Rojas-Soto, 2012; Pearson, 2010). This is particularly applicable to rare and/or endangered species, where their conservation status is often closely linked to their extent of occurrence (IUCN Standards & Petitions Committee, 2019). Many species lack suitable quantitative data from which their distributions can be directly inferred as a consequence of their rarity, cryptic or secretive behaviour, low population densities or nocturnal activity patterns, necessitating the use of alternative mapping methods (Ashcroft et al., 2012; Clements et al., 2012; Collins & du Toit, 2016; Jackson & Robertson, 2011; Roberts et al., 2016; Sattler et al., 2007; Thorn et al., 2009).

Species distribution modelling (SDM) is a statistical technique that is often used in biogeography, habitat and species management, conservation biology and planning as it provides estimates of a species' occurrence in regions where no systematic sampling has been performed, or for species that are difficult to detect and survey (Bland et al., 2014; Breiner et al., 2015; Butchart & Bird, 2010; Clements et al., 2012; Guisan & Thuiller, 2005; Guisan et al., 2013; Guisan & Zimmermann, 2000; Kershaw et al., 2013; Pearson et al., 2007; Roberts et al., 2016; Sattler et al., 2007; Thorn et al., 2009). Species distribution modelling compares biotic and abiotic conditions at known occurrence points to background points where the species of interest has not yet been recorded, extracts those variables that are most informative of the species' occurrence and uses these predictive variables to infer other regions with suitable conditions where the species may occur (Barve et al., 2011; Breiner et al., 2015; Elith & Leathwick, 2009; Pearson et al., 2007; Phillips et al., 2006; Phillips & Dudík, 2008). Species distribution models are especially useful for species that have limited distribution data available, as georeferenced data from a variety of sources can be used and the resultant predicted distributions can guide future surveys and conservation initiatives (Guisan et al., 2013; Pearson et al., 2007; Rodríguez et al., 2007).

Temminck's pangolin (*Smutsia temminckii*) is one of eight pangolin species occurring globally, four of which occur in Africa (Challender et al., 2014). *Smutsia temminckii* has a wide distribution, occurring from South Sudan and southern Chad to the northern provinces of South Africa (Pietersen et al., 2019). They are solitary and predominantly nocturnal myrmecophagous mammals whose elusive behaviour and low population densities make them inherently difficult to study (Heath & Coulson, 1997; Pietersen et al., 2014a, 2016a; Richer et al., 1997; Swart et al., 1999; Willcox et al., 2019). Because of these difficulties, their distribution is not well-known and a recent targeted study in the Northern Cape Province of South Africa greatly expanded their known distribution in this country (Pietersen, 2013), suggesting that this species' distribution may be greater than currently appreciated. Owing to their secretive nature and low population densities, it is not feasible to directly survey *S. temminckii*, and thus, alternative methods are required to predict their distribution.

Although widespread across the African continent, *S. temminckii* is listed both globally and nationally in South Africa as Vulnerable on the IUCN Red List of Threatened Species™, with a population that is predicted to decrease by 30%–40% over the next three generations (Pietersen et al., 2016b, 2019). The major threats to this species include exploitation for traditional medicines, talismans and as a source of protein, habitat loss, accidental electrocution on electrified fences and road mortalities (Pietersen et al., 2016b, 2019). In South Africa, *S. temminckii* is restricted to the northern and eastern regions, occurring marginally into KwaZulu-Natal Province (Pietersen et al., 2016b, 2019). There are various historical accounts of the distribution of *S. temminckii* in South Africa, with a number of these reported locations falling outside of the currently accepted range of this species (see, for example, Lloyd & Millar, 1983; Lynch, 1975, 1989; Roberts, 1951; Skinner et al., 2004; Stuart, 1980). In addition, several contemporary sight records also fall outside of this species' accepted distribution to varying degrees. Although most of these questionable records have been assumed to be erroneous and excluded from this species' distribution in all major works to date (see, for example, Pietersen et al., 2016b, 2019), no attempt has yet been made to assess their veracity.

We compared the past (pre-2002), contemporary (post-2001) and overall predicted distribution of *S. temminckii* in South Africa to assess the probable validity of the questionable historical and contemporary records and also compared the predicted distribution to the IUCN range map to investigate whether this species' distribution in South Africa is larger than currently depicted. Additionally, we assessed whether there has been a range shift over time by dividing our data set into two time periods coinciding with a previous National Red List Assessment of the species that incorporated data up to the year 2002 (Friedmann & Daly, 2004).

2 MATERIALS AND METHODS

Presence-only occurrence records were compiled from the literature, provincial threatened species databases, citizen science databases (supported by photographic evidence) and our own field data. All records were georeferenced and where georeferencing came from a database the coordinates were verified for accuracy. Any records that could not be reliably georeferenced were removed from the data set. As species distribution models perform better if geospatially correlated observations are removed (Boria et al., 2014; Brown, 2014), we filtered the data set to include only records that were separated by a distance of at least 10 km by placing a 5 km radius buffer around all occurrence points in Quantum GIS v. 3.4 and removing one sighting of each pair of overlapping buffers. The filtered database was further divided into records originating before the year 2002 and those dating from 2002 onwards, as a previous National Red List Assessment of the species incorporated data up to the year 2002 (Friedmann & Daly, 2004). Therefore, partitioning the data set into pre-2002 and post-2001 records allowed us to investigate potential range shifts since that assessment. The three final data sets comprised $n_{\text{pre-2002}}$ = 168, $n_{\text{post-2001}}$ = 140, and n_{all} = 259 sightings, respectively. An additional fourteen historical records (two literature records with associated museum specimens, three literature records without associated museum specimens and nine sight records) and four contemporary sight records which we deemed questionable as they occurred outside of the currently accepted distribution and/or in seemingly unsuitable habitat were not included in the models.

Five bioclimatic variables (annual mean temperature, mean diurnal range, maximum temperature of warmest month, minimum temperature of coldest month and annual precipitation) were selected *a priori* based on the known ecology of the species and downloaded from the WorldClim version 2.0 database (Fick & Hijmans, 2017). We additionally included dominant soil type (Batjes, 2004), vegetation type and bioregion (Mucina & Rutherford, 2006) and veld type (Acocks, 1988) to construct the models (Table 1). Vegetation type, bioregion and veld type were all included as they represent the flora of South Africa at different scales, with veld type classifying the flora into broader categories (*n* = 70; Acocks, 1988) while vegetation type describes dominant plant species at a much finer scale (*n* = 437 categories; Mucina & Rutherford, 2006). Bioregions are defined on the basis of having similar biotic and physical features and processes at the regional level and are units of classification in between biomes and vegetation types, with 35 bioregions being recognised in South Africa (Mucina & Rutherford, 2006).

TABLE 1. Environmental variables used to model the distribution of Temminck's pangolin (*Smutsia temminckii*) in South Africa

Variable	Definition
BIO 1	Annual mean temperature
BIO 2	Mean diurnal temperature range
BIO 5	Maximum temperature of warmest month
BIO 6	Minimum temperature of coldest month
BIO 12	Annual precipitation
Dominant soil	Dominant soil type
Vegetation type	Vegetation of South Africa (Mucina & Rutherford, 2006)
Bioregion	Bioregion *fide* Mucina and Rutherford (2006)
Veld Type	Veld Types *fide* Acocks (1988)

Note

Variables in bold were used in the final models.

Predictor variables were re-sampled to 30 arc-second (1 km^2) resolution to match the resolution of the bioclimatic variables and were tested for autocorrelation in ENMTools 1.3 (Warren et al., 2010; Warren & Seifert, 2011). Variables that were correlated ($r \geq |0.7|$, $n = 4$) were removed since they contain information that is already present in other layers (Brown, 2014; Chalghaf et al., 2016; Elith et al., 2011). As all the bioclimatic variables were correlated ($r > 0.7$), we only retained annual precipitation in the final models.

Species distribution modelling was performed in MaxEnt version 3.3.3 k (Phillips & Dudík, 2008; Phillips et al., 2004, 2006). MaxEnt is one of the most versatile and widely used modelling software programmes as it is known to cope well with small data sets, as well as when using a small number of predictor variables (Bean et al., 2012; Hernández et al., 2006; Jackson & Robertson, 2011; Phillips & Dudík, 2008; Warren & Seifert, 2011). We ran MaxEnt with default settings, a logistic output format, 10-fold cross-validation to estimate errors around fitted functions and a maximum of 500 iterations. We varied the regularisation multiplier between one and five to constrain MaxEnt and help prevent over-fitting of the models, with model performance assessed using the area under the receiver operating curve (AUC), which is the most widely used model selection criterion (Breiner et al., 2015; Marmion et al., 2009; Warren & Seifert, 2011). The AUC value varies from 0 to 1, with models having an AUC value ≥0.7 considered to be robust (Marmion et al., 2009).

We initially modelled the distribution of *S. temminckii* using all the non-correlated variables (annual precipitation, vegetation type, veld type, bioregion and soil type). However, these models resulted in poor predictive power which was largely attributable to the relatively coarse scale of the bioregion variable. Bioregion was thus removed from all subsequent models while veld type was retained, despite it being a more dated classification. A regularisation multiplier of one resulted in over-fitting of the data, while a value of five reduced the specificity of the resultant models. We therefore used a regularisation multiplier of three for all three final models, which showed the greatest predictive power while limiting non-specific projection.

3 RESULTS

The occurrence records that were used for modelling were fairly evenly distributed across the known range of this species, thereby precluding any spatial autocorrelation. The models for all three data sets (pre-2002, post-2001 and all) performed well, with AUC values of 0.846 ± 0.037, 0.881 ± 0.035 and 0.888 ± 0.030 for overall, historical sightings and contemporary sightings, respectively. Veld type contributed the most to the predictive power of all models, followed by either soil type or vegetation type. Annual precipitation consistently contributed the least to the predictive power of all models.

All three time periods showed a similar pattern, with *S. temminckii* predicted to inhabit most of the Northern Cape Province north of the Orange River and east of Namaqualand, extending through northern North West Province and most of Limpopo Province (but absent from the high-lying Eastern Escarpment) and through the Mpumalanga Province Lowveld into extreme northern Kwazulu-Natal Province (Figure 1). There has been a purported westward shift in this species' range between the two periods examined (pre-2002 and post-2001), with *S. temminckii* predicted to be largely absent from the Northern Cape Province prior to the year 2002 (Figure 1b), while expanding into the Northern Cape Province while decreasing its range in Limpopo Province since the start of 2002 (Figure 1c).

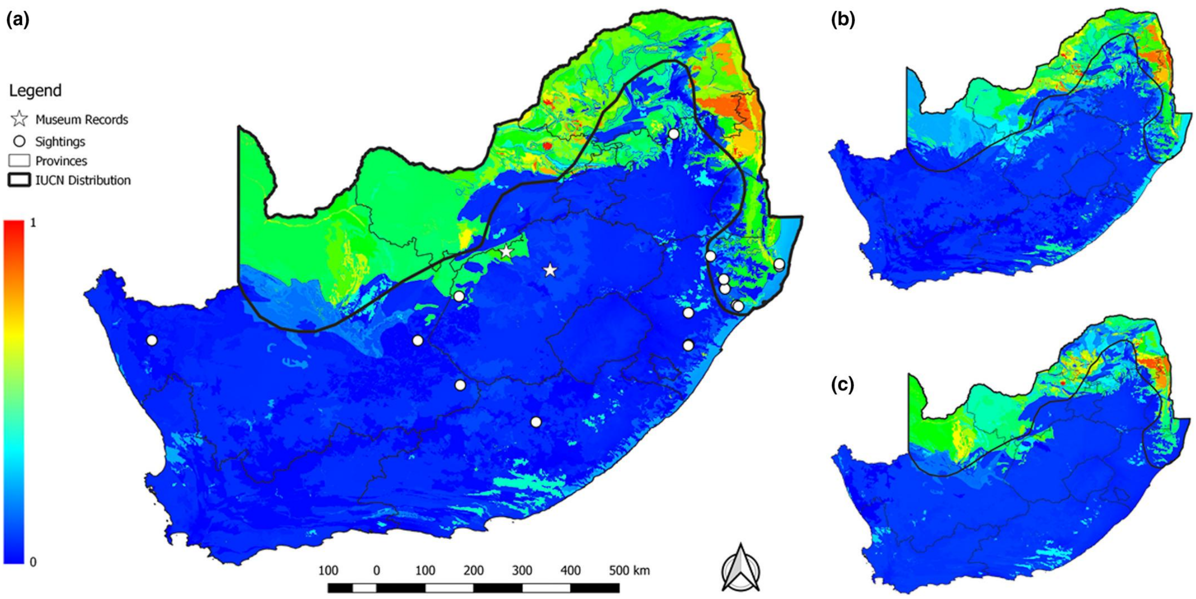

FIGURE 1. Predicted distribution of Temminck's pangolin (*Smutsia temminckii*) in South Africa using (a) all 259 accepted georeferenced locality records across all periods, (b) 168 historical (pre-2002) occurrence records and (c) 140 contemporary (post-2002) occurrence records. White stars indicate questionable museum records, and white circles indicate questionable sight records, neither of which were included in the predictive models. The IUCN distribution for this species is indicated with a thick dark line. Warmer colours indicate a higher probability of occurrence. (For interpretation of the colours on this image, the reader is directed to the online version of this article)

Of the fourteen historical and four contemporary records that we initially considered dubious (i.e. historical records with questionable localities and contemporary sightings lacking photographic evidence) and excluded from the models, nine fall within, or in close proximity to, the modelled distribution of this species (Figure 1a). One of the historical records, which is supported by a museum voucher specimen, occurs within the predicted distribution of this species, while the second museum record occurs well outside of the predicted distribution (Figure 1a). Two historical (pre-2002) literature records and five historical sight records occur on the border of the predicted distribution, as do two contemporary (post-2001) sight records. The remaining five historical and two contemporary records occur well away from this predicted distribution (Figure 1a).

The predicted overall distribution closely mirrors the IUCN range map, which was created by drawing a minimum convex polygon around all the verified distribution points (Pietersen et al., 2019). Our modelled distribution does, however, predict some additional suitable habitat in parts of the Limpopo and north-western Mpumalanga provinces, as well as in extreme eastern North West Province, northern Gauteng Province and northern Free State Province (Figure 1a).

4 DISCUSSION

Smutsia temminckii is predicted to be widespread in the northern portions of South Africa, although being largely absent from high-lying grasslands and exceedingly arid regions. The apparent contemporary (post-2001) range shift into the Northern Cape Province and the concomitant reduction in range in the Limpopo Province are likely artefacts of the data rather than representing a genuine range shift. This species was virtually unknown from the Northern Cape Province prior to 2010 (Skinner et al., 2004; but see Stuart, 1980). Subsequent fieldwork in the Northern Cape Province by Pietersen (2013) led to numerous distribution records being received from this region, while the relative lack of contemporary sightings from Limpopo Province, a region with numerous sightings in the pre-2002 data set, likely explains this apparent range shift over time.

The model results enabled us to evaluate the validity of several historical localities that were deemed to be erroneous given the current understanding of this species' distribution. The all-encompassing model suggests that at least one of the historical museum records (Farm Elizabethsrust 47, Hoopstad district; Lynch, 1975) falls within the predicted distribution of this species and the collection locality is therefore probably valid. The second historical museum record (Ventersburg; Lynch, 1975) is 58 km south-east of the nearest predicted distribution of this species and is well within the known dispersal capabilities of this species (van Aarde et al., 1990; Pietersen et al., 2014a). This locality is possibly also genuine, although it may refer to a dispersing juvenile or roving male rather than a resident population (see Pietersen et al., 2014a) but it may equally refer to an imprecise collecting locality. The historical sight record from the farm Kalkoenkrantz 169 in the Eastern Cape Province (Lynch, 1989) falls well outside of the predicted distribution of this species and should be considered a misidentification and probably refers to an aardvark (*Orycteropus afer*). Similarly, Roberts' (1951) record from Colesberg also falls well outside of the predicted distribution of this species and should be considered a misidentification or an erroneous collecting locality. The McGregor Museum expedition's record from just south of Hope Town, Northern Cape Province, is ca. 130 km south of the nearest contiguous predicted range. Although falling outside of the predicted range, this distance is well within the dispersal capabilities of this species, and in light of the competence of the observers, we suggest that this record tentatively be treated as genuine, although again possibly referring to a dispersing juvenile or roving male rather than a self-persisting population (see Pietersen et al., 2014a). A contemporary sighting from Goegap Nature Reserve, Northern Cape Province (M. Coetzee, pers. comm. 2014), should be treated as erroneous pending substantiating evidence of this species' presence here.

Our models suggest that additional suitable habitat exists in both Limpopo and Mpumalanga provinces. There is both a historical (Rautenbach, 1982) report and a contemporary (P. Vosser, pers. comm. 2015) report of this species in the vicinity of Roossenekal in Mpumalanga Province near its border with Limpopo Province, with this area falling within the predicted distribution of this species but outside of the IUCN range map. This area has experienced a high rate of habitat conversion and supports a relatively high human and agricultural density (Reyers, 2004), and as such, *S. temminckii* may now be restricted to pockets of natural vegetation and protected areas in this region. Recent sightings in and adjoining False Bay National Park (J. Cuthbertson, pers. comm. 2014) in KwaZulu-Natal Province are on the eastern predicted range of this species and may therefore be valid, and are further supported by a historical sight record from the False Bay National Park (Pringle, 1974). Two sightings in KwaZulu-Natal Province near the southernmost extreme of this species' IUCN distribution were made by Ezemvelo KwaZulu-Natal Wildlife staff and fall within the predicted distribution of this species, albeit at the extreme edge. Both observations were by knowledgeable staff members, and although there is no supporting photographic evidence, the described behaviour supports the initial identification and rules out most other potential species. The remaining three sightings near the western extreme of this species' plotted IUCN distribution in KwaZulu-Natal Province are all relatively close to its predicted distribution and are therefore likely valid. The three sightings falling outside of the IUCN distribution in KwaZulu-Natal Province (two sightings in the Zinti Valley and one near Muden) are outside of the predicted distribution, and although the distance from the predicted distribution and confirmed sightings (ca. 150 and 100 km, respectively) is within the known dispersal range of this species (van Aarde et al., 1990; Pietersen et al., 2014a), the habitat in which they were seen and the described behaviour suggests that these three sightings need to remain unconfirmed until additional evidence comes to light.

A questionnaire survey of the occurrence of selected mammals in the Western, Eastern and Northern Cape provinces conducted by Lloyd and Millar (1983) suggested that *S. temminckii* is fairly widespread across the Eastern and Northern Cape provinces, extending from near the coast in the south-east to the Botswana and Namibia borders in the north-west, although being more predominant in the north. Based on the results of our models, we suggest that the records from the Eastern Cape Province and the Northern Cape Province south of the Orange River are erroneous and probably refer to misidentifications or respondent's confusion of vernacular names during the survey. A similar conclusion was reached by Stuart (1980) who, following a personal communication from P. Lloyd, conducted follow-up interviews with many of the farmers who initially reported *S. temminckii* from their properties during Lloyd and Millar's (1983) survey and determined that in most cases the respondents had actually referred to *O. afer*.

All of our models suggest that the Free State Province has always been marginal for this species, despite claims that they were historically widespread in the province (Skinner et al., 2004; Stuart, 1980). Similarly, KwaZulu-Natal Province is unlikely to have harboured a significant population in the past. Although some authors contend that this species is ecologically extinct in KwaZulu-Natal Province (Kyle, 2000; Pietersen et al., 2014b, 2016b), recent sightings of naturally occurring individuals coupled with this species' low detection rate suggest that it still persists in this province, possibly even at historical densities.

Our results suggest that the current accepted distribution of *S. temminckii* in South Africa is relatively accurate and that little additional suitable habitat is available for this species. As all species are inherently dependant on their food source for their survival, it would be insightful for future studies to include the distribution of the main ant and termite prey species as predictor variables to assess their relative importance in governing the range of *S. temminckii*, as well as to investigate the interplay between these and the other predictive variables. Owing to the added burden that climate change and a burgeoning human population is predicted to have on agriculture (Olesen & Bindi, 2002; Parry et al., 1999), it will be informative for future studies to model the potential future distribution of this species in relation to those areas predicted to be suitable for crop agriculture and to assess what the implications are for this species' future distribution.

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