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Meng, Han, Carr, Jamie, Beraducci, Joe et al. (17 more authors) (2016) Tanzania's reptile biodiversity : Distribution, threats and climate change vulnerability. Biological Conservation. pp. 72-82. ISSN 0006-3207

https://doi.org/10.1016/j.biocon.2016.04.008

Tanzania's Reptile Biodiversity: Distribution, Threats and Climate Change Vulnerability

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Key words: Species Richness, Red List, Traits, Protected Areas, Endemism, Conservation Priority

Abstract

Assessments of biodiversity patterns and threats among African reptiles have lagged behind those of other vertebrate groups and regions. We report the first systematic assessment of the distribution, threat status, and climate change vulnerability for the reptiles of Tanzania. A total of 321 reptile species (including 90 Tanzanian endemics) were assessed using the global standard IUCN Red List methodology and 274 species were also assessed using the IUCN guidelines for climate change vulnerability. Patterns of species richness and threat assessment confirm the conservation importance of the Eastern Arc Mountains, as previously demonstrated for birds, mammals and amphibians. Lowland forests and savannah-woodland habitats also support important reptile assemblages. Protected area gap analysis shows that 116 species have less than 20% of their distribution ranges protected, among which 12 are unprotected, eight species are threatened and 54 are vulnerable to climate change. Tanzania's northern margins and drier central corridor support high numbers of climate vulnerable reptile species, together with the eastern African coastal forests and the region between Lake Victoria and Rwanda. This paper fills a major gap in our understanding of the distribution and threats facing Tanzania's reptiles, and demonstrates more broadly that the explicit integration of climate change vulnerability in Red Listing criteria may revise spatial priorities for conservation.

1 Introduction

Tanzania (Fig. 1) is characterised by a diverse range of landscapes and habitats, from mangroves through diverse savannah and forest habitats to alpine grasslands (Burgess et al., 2004). Some regions, for example the Eastern Arc Mountains, are thought to have acted as both refuges and areas of speciation during climatic cycles (Fjeldså and Lovett, 1997; Tolley et al., 2011). Tanzania's central arid region is regarded as an important element of Africa's 'Arid Corridor', facilitating faunal movements between the Namib in the south and Horn of African in the north (Bobe, 2006; Broadley, 2006). However, there is no documentation of vertebrate biodiversity patterns at the Tanzanian national scale, with studies focused on more local biodiversity centres (e.g. Eastern Arc: Rovero et al., 2014; Coastal Regions: Burgess and Clarke, 2000), or at regional (e.g. African: Brooks et al., 2001; Burgess et al., 2004; Platts et al., 2014) or global scales (Pimmet al., 2014). As Tanzania is party to many global conventions, in particular the Convention of Biological Diversity, the lack of appropriate data on biodiversity patterns and threats hinders the development of National Biodiversity Strategies and Actions Plans, and other national policy instruments.

The IUCN Red List of Threatened Species (hereafter 'the Red List') provides the most widely-

doi:10.1016/j.biocon.2016.04.008

accepted framework for assessing the types and severity of threats to the survival of individual species (IUCN Standards and Petitions Subcommittee, 2014). Species distribution maps compiled during the Red Listing process, using primary data and expert knowledge, represent a species' known global range. In addition, the Red List system also gathers data of threats to species, which is being augmented to explicitly consider the threats from climate change (Carr et al., 2013; Foden et al., 2013). This development addresses some of the limitations of the Red List (Akçakaya et al., 2006) and acknowledges that climate change poses an increasingly significant threat to species.

Reptiles occur throughout Tanzania, with the exception of areas above the snowline (Spawls et al., 2002). Some reptile species have very small, restricted ranges and rely upon highly-specific environmental conditions, such as rainfall and temperature regimes and/or specific habitats in order to undergo particular life-history events (e.g. Zani and Rollyson, 2011; Weatherhead et al., 2012). Others, such as viviparous reptiles need to balance thermal budgets between normal daily activities and reproductive demands. As such, reptiles are particularly sensitive to changes in insolation (Sinervo et al., 2008) and may be especially vulnerable to climate change (Whitfield Gibbons et al., 2000).

Protected areas are an important conservation approach to preventing biodiversity loss. However, the coverage of an existing protected area network, for example in Tanzania, does not always reflect the distribution of species that may require protection with urgency (e.g. Sritharan and Burgess, 2012). These gaps can be caused by various factors during the protected area planning stage, such as not prioritising threatened or endemic biodiversity patterns, not considering global climate change as a threat, and biases towards areas that can least prevent land conversion (Rodrigues et al., 2004; Joppa and Alexander, 2009).

In this paper we present new and existing reptile data for Tanzania to show: a) species richness; b) richness of threatened species; and c) richness of species considered vulnerable to climate change. Reptile distribution patterns are compared with those for birds, mammals and amphibians to determine if biodiversity patterns are congruent between vertebrate groups. Gaps within Tanzania's protected area network are identified by evaluating the extent of reptile range overlap with protected areas. We also present knowledge-gaps that need to be filled for more effective conservation practices in the future. Our analyses are targeted at policy-makers and planners, and aim to facilitate the consideration of biodiversity in planning and conservation decision making and the better understanding of future protection requirements.

doi:10.1016/j.biocon.2016.04.008

2 Data and Methodology

2.1 Species data and the Red List assessment process

Species data came from two sources: i) an IUCN Red Listing Workshop in Bagamoyo, Tanzania (January 2014); and ii) published IUCN Red List assessments. Nine expert herpetologists (from the author list: CM; IS; JCh; JB; KH; PM; PW; SS; WB) attended the 2014 workshop where they completed the standard IUCN Red Listing process (IUCN Standards and Petitions Subcommittee, 2014; IUCN, 2015) and also provided climate change vulnerability-related trait information (see Section 2.2). Prior to this workshop a total of 37 Tanzanian reptile species (excluding marine species) had been assessed for the IUCN Red List, although many were considered in need of updating.

The preliminary list of Tanzanian reptile species was derived from Spawls et al. (2002) and Menegon et al. (2008). This was cross referenced against field guides and atlases from other regions of Africa that share species with Tanzania (Southern Africa — Branch, 1998; West Africa — Trape et al., 2012a; Trape and Mané, 2006a; Cameroon — Chirio and LeBreton, 2007; Ethiopia — Largen and Spawls, 2010; Somalia — Lanza, 1990), and the Reptile Database (http://www.reptile-database.org) (Uetz and Hošek, 2013) was used to identify more recent descriptions. Inconsistencies between these lists were referred to experts for resolution. A number of major taxonomic studies and revisions have been undertaken since Spawls et al. (2002); key references consulted in this regard include Broadley and Wallach (2007, 2009: *Typhlopidae*); Adalsteinsson et al. (2009: *Leptotyphlopidae*); Trape et al. (2006: *Atractaspis*); Trape and Mané (2006b); Trape et al. (2012b) (*Dasypeltis*) and Kelly et al. (2008: *Psammophiidae*). One species, *Agama dodomae*, was included prior to its formal description following discussions with the describing author, as the description was due to be published prior to finalisation of the Red List results (Wagner, 2014). Species lists for chameleons, pythons and vipers were confirmed by the relevant IUCN SSC Specialist Groups.

Reptile range maps are presented on a 10 arc-minute grid (c. 19 km at the equator). To reduce errors of commission, we removed grid cells containing no elevations or habitat types deemed suitable for the species, following the procedure used for other taxa (Rondinini et al., 2005; Foden et al., 2013).

Through this process, we compiled distributional data for 279 of the 321 reptile species known to occur in Tanzania (Table 1), spanning 26 families and 102 genera (Table 2). We compiled Red List data for all 321 species, providing 184 published assessments and 137 ‘draft’ assessments (i.e. currently unpublished; Table A1, Annex 1).

doi:10.1016/j.biocon.2016.04.008

To investigate the spatial congruence of reptile species richness and richness in other vertebrate groups, we obtained range maps for 188 amphibian, 356 mammal, and 1046 bird species, all recorded as occurring in Tanzania, from the IUCN Red List of Threatened Species (IUCN, 2015) (http://www.iucnredlist.org/technical-documents/spatial-data). For consistency with reptile richness, individual species maps were gridded at 10 arc-minute resolutions and summed over species within a group. We summarised spatial congruence between group richness using a Taylor diagram (Taylor, 2001), which normalises richness in each group to the interval [0,1], and then plots a comparison of standard deviations, Pearson correlations and centred root-mean-squared differences between reptile richness and richness in other groups (Taylor, 2001). Due to potentially confounding effects of spatial autocorrelation, values of Pearson's r were checked against those derived from spatially random samples of 30 cells (1% of the total), such that the mean distance (km) between adjacent sampling points was 101 ± 10 s.d. over 10,000 repetitions.

2.2 Climate change vulnerability

We applied the IUCN Climate Change Vulnerability Assessment Framework (Carr et al., 2013, 2014; Foden et al., 2013) to 274 reptile species (Table 1). This framework uses biological traits and ecological requirements (hereafter 'traits') to infer high sensitivity and/or low adaptive capacity to climate change, together with measures of individual species' projected exposure to change, to develop an overall insight into each species' relative vulnerability to climate change.

We gathered data on 11 individual traits across four trait groups (referred to as 'level 1' in Table A2.2, Annex 2) to identify species with high sensitivity to climate change: (i) specialised habitat/microhabitat requirements; (ii) narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle; (iii) dependence on a specific environmental trigger (e.g. for migration or reproduction) that is likely to be disrupted by climate change; and (iv) dependence on inter-specific interactions, likely to be disrupted by climate change. To assess poor adaptive capacity, we used five individual traits across two level 1 trait groups (Table A2.3, Annex 2): (i) poor dispersability; (ii) poor evolvability, defined as low capacity to adapt in-situ through genetic micro-evolution, based on proxies relating to a species' reproductive output and/or generation length. Species possessing at least one trait under either of these two components were considered to have high climate sensitivity or low adaptive capacity, according to the respective trait (Foden et al., 2013).

Species' exposure to climate change was assessed by overlaying projected changes in biologically-

doi:10.1016/j.biocon.2016.04.008

relevant climatic variables on species' distribution maps (Table A2.1, Annex 2). Climate grids for 1950–2000 were from WorldClim (Hijmans et al., 2005). For consistency with climate change vulnerability assessments of other groups (amphibians, birds and mammals), we used mean values to resample WorldClim grids from 30″ (c. 1 km) to 10′ (c. 19 km). For future climate (2041– 2070 and 2071–2100) we used data from AFRICLIM v1 (Platts et al., 2015), which provides high-resolution ensemble means derived in a two-step downscaling procedure from eight CMIP5 General Circulation Models (GCMs): CanESM2, CNRM-CM5, EC-EARTH, GFDL-ESM2G, HadGEM2-ES, MIROC5, MPI-ESM-LR and NorESM1-M. First, each GCM was dynamically downscaled to a resolution of 0.44° (c. 50 km) using the SMHI-RCA4 regional climate model, in order to better capture climatic processes operating at sub-GCM scales. Second, regional outputs were empirically downscaled (bias-corrected) against the WorldClim baselines (Platts et al., 2015). Two representative concentration pathways (RCPs) of the IPCC-AR5 were considered, characterising a stabilisation of radiative forcing shortly after 2100 (RCP4.5) or increasing greenhouse gas emissions over time (RCP 8.5) (van Vuuren et al., 2011).

Using these data, we calculated the projected changes in four variables: (i) absolute change in mean temperature; (ii) ratio of change in total precipitation; (iii) absolute change in temperature variability (calculated as the average absolute deviation from the mean); and (iv) ratio of change in precipitation variability (calculated in the same manner as iii). A species was designated as ‘highly exposed’ if its exposure with respect to any of these variables exceeded a given threshold. Following Foden et al. (2013) and other applications of the IUCN Climate Change Vulnerability Assessment Framework (e.g. Carr et al., 2013, 2014), thresholds were fixed across scenarios, at levels determined by the quartile of most severely exposed species under RCP4.5 (2041-2070).

Assessments of sensitivity, adaptability and exposure to climate change were combined to determine each species' overall vulnerability. Following Foden et al. (2013), only species scoring ‘high’ in all three components were considered to be climate change-vulnerable. Of the 274 species assessed for climate change vulnerability, 113 (41.2%) and 56 (20.4%) had unknown final adaptability and sensitivity scores, respectively (i.e. data were unavailable for at least one trait, and assessments were scored ‘low’ for all other traits in that group; see Table A3, Annex 3). To account for these missing trait data, we ran each assessment twice, assuming each missing data point as either ‘low’ (optimistic scenario) or ‘high’ (pessimistic scenario).

2.3 Protected area gap analysis

Using all species distribution data, we assessed the degree of overlap with protected areas (WDPA;

doi:10.1016/j.biocon.2016.04.008

IUCN and UNEP-WCMC, 2014). Protected areas with only location (no boundary) information were omitted from the analysis as it was not possible to calculate their overlap with species' ranges. All categories of protected area were included (618 polygons in total). This protected area network consists of 14 designation category types, with Forest Reserves comprising the majority (498; 80% of protected areas).

For each reptile species, we calculated protected area coverage within arbitrary protection thresholds of 0–10% and 10–20% of the respective species' range. These thresholds are not specific to the levels of habitat availability or integrity required for species' survival, but highlight generally low levels of protection that may be targeted for intervention on a site-by-site or species-by-species basis.

3 Results

The overall distribution pattern of reptile species richness highlights the Eastern Arc Mountains and the central and eastern regions of Tanzania as centres of reptile diversity (Fig. 2). Reptile richness is strongly correlated with amphibian richness (Pearson's $r = 0.61$ on both the full dataset and under subsampling), moderately correlated with bird richness ($r=0.45$ [0.38 under subsampling]), and weakly correlated with mammal richness ($r= 0.14$ [0.21 under subsampling]).

Ninety (28%) reptile species are endemic to Tanzania (Table A1, Annex 1). A particularly diverse and endemic-rich group is the chameleons, with 24 endemics out of 39 species in total. Other diverse genera include the geckos *Lygodactlylus* (17 species in total) and *Hemidactylus* (7), the scincid genus *Trachylepis* (11), and the fossorial skink genera *Melanoseps* (7) and *Scolecoseps* (2). Tanzania's terrestrial and arboreal snake fauna also contains high diversity within the genera *Philothamnus* (11), *Psammophis* (10) and *Lycophidion* (9), as do burrowing snakes, such as the scolecophidian genera *Afrotyphlops* (6) and *Leptotyphlops* (9).

3.1 Diversity and distribution of threatened reptiles

Forty-two (13%) reptile species are (provisionally, pending final reviewand publication) considered to be globally threatened with extinction (Vulnerable, Endangered or Critically Endangered), and 36 (11%) have been assessed as Data Deficient (Table A1, Annex 1).

The highest concentrations of threatened species (up to 16 species per grid cell) are found in the Eastern Arc Mountains, especially the East Usambara Mountains near Tanga and the Uluguru Mountains near Morogoro (Fig. 3a, b). Other montane areas, such as Mt. Kilimanjaro, the Udzungwa

doi:10.1016/j.biocon.2016.04.008

Mountains and the Nguru Mountains, have up to eight threatened reptile species per grid cell. Other montane or coastal locations (Katavi, Rukwa, Lindi, Pwani, Mbeya and Njombe) contain one or two threatened species per grid cell. These patterns generally follow those of other vertebrate groups, with the East Usambara and Uluguru mountains always being prioritised, but the relatively low ranking of the Udzungwa Mountains differs from other groups where this mountain is normally the most important (see Rovero et al., 2014).

Our assessment of non-climatic threats to reptiles shows that 'agriculture/ aquaculture' and 'biological resource use' present the most significant threats (Table 3). Within these broad classifications, 'smallholder farming', 'logging and wood harvesting' and 'hunting and trapping' (both for 'intentional use' and for 'persecution/control') are common threat types.

The international pet trade poses a threat to some restricted-range reptile species, including Tanzanian endemics. In Tanzania, the majority of chameleon species are traded, often at unsustainable levels. The turquoise dwarf gecko (*Lygodactylus williamsi*) (Critically Endangered) is currently collected at unsustainable levels (Flecks et al., 2012). The pancake tortoise (*Malacochersus tornieri*) is also threatened by the pet trade (Klemens and Moll, 1995; UNEP-WCMC, 2015). Savannah-endemic species, such as Agama dodomae, are collected and traded in high and potentially unsustainable numbers (Wagner, 2010).

3.2 Diversity and distribution of climate change-vulnerable reptiles

For the period 2041–2070, using climate projections based on the RCP4.5 emission pathway a total of 186 species (68%) were considered as 'high' and 87 species (32%) as 'low' in terms of their projected exposure to climate change (Table A2.1, Annex 2). One species (b1%) was 'unknown', and this remained across all combinations of time periods and emissions pathways. For the period 2071 to 2100, based on RCP 4.5 (but using the same thresholds determined for the above results), 270 species (98.5%) were considered 'high' and three (1%) as 'low'. Using RCP 8.5, for both time periods, and again using the same thresholds, 273 species (> 99%) were considered 'high' and zero as 'low'.

A total of 194 reptile species (71% of the 274 assessed) possess traits that make them sensitive to climate change (Table A2.2, Annex 2). Within our analysis the most common traits were habitat specialization (Trait S1; 117 species; 43%) and dependence upon specific microhabitats (Trait S2; 72 species; 26%). Data gaps on the sensitivity of reptile species were most common when considering environmental cues and triggers that may be disrupted by climate change (Trait S8) and negative

doi:10.1016/j.biocon.2016.04.008

species interactions that may increase as a result of climate change (Trait S11), which were unknown for 116 (42%) and 126 (46%) species, respectively.

One hundred and fifty-nine species (58%) were assessed as possessing traits that make them poorly able to adapt to climate change (Table A2.3, Annex 2). Among these traits, a low intrinsic capacity to disperse (Trait A2) was the most common, present in 136 species (50%). Data for traits relating to a species' capacity to adapt to change in-situ through genetic micro-evolution (Traits A4 and A5) were missing in many cases: information on reproductive output (Trait A4) was unavailable for 240 species (88%), and information on species maximum longevity (a proxy for generation length (Trait A5)) was unavailable for 264 species (96%).

When combining the exposure, sensitivity and adaptive capacity components, 86 (31%) or 175 (64%) reptile species were considered vulnerable to climate change by 2041–2070, using climate projections based on the RCP4.5 emissions pathway, and an optimistic or pessimistic assumption of missing data values, respectively (Fig. 4; Table A3, Annex 3). These numbers increase to 125 (46%) (optimistic) or 248 (90.5%) (pessimistic) under rising emissions (RCP 8.5), and to 122 (45%) (optimistic)/245 (89%) (pessimistic) or 125 (46%) (optimistic)/ 248 (90.5%) (pessimistic) by 2071–2100 for RCP 4.5 and RCP 8.5, respectively (Table A3, Annex 3).

Focusing on mid-century (2041–2070) under RCP 4.5, which we consider more immediately relevant to conservation, the highest concentrations and proportions of climate change-vulnerable reptile species (up to 18 species per grid cell) are found in the dry habitats of northern Tanga (Fig. 3c, d). A broad area with 10 to 13 climate change-vulnerable reptile species per grid cell is found in the northeastern (bordering Kenya) and eastern (coastal and inland) parts of Tanzania. There are also regions of importance in Kagera, Rukwa, Dodoma, Morogoro and the islands of Zanzibar, Pemba and Mafia. These trends, although not absolute numbers, are consistent across emissions pathways (RCP 4.5 or RCP8.5) and time-spans (2041–2070 or 2071–2100), and under different assumptions for missing data values (Table A3, Annex 3). Note, however, that maps are only presented for the RCP 4.5/2041–2070 combination). These areas are not congruent with areas highlighted previously as containing high numbers of threatened species, a point which is discussed later in this paper.

3.3 Gaps in Tanzania's protected area network

Of the assessed reptile species with available distribution maps, 116 (42%) have less than 20% of their Tanzanian ranges protected by the current protected area network (54 of these with b10%). Of the species with < 20% protected, eight are threatened, and 54 to 70 (or 47–60%) are vulnerable to

doi:10.1016/j.biocon.2016.04.008

climate change under the RCP 4.5/2041–2070 to RCP 8.5/2071–2100 combinations (Table 4). Four Tanzanian endemic species have no protection at all: *Chirindia ewerbecki, Chirindia mpwapwaensis, Ichnotropis tanganicana* and *Melanoseps pygmaeus*.

Gaps in the current protected area network were located in places that host high proportions of globally threatened and climate change vulnerable species (Fig. 5). This includes mountain areas north of Lake Malawi (Southern Highlands), large parts of the Eastern Arc Mountains, as well as some small coastal forest patches (southern Lindi and southern Liwale) in the south-eastern part of the country.

Based on the above results, we identified nine species that are globally threatened, endemic to Tanzania and climate change-vulnerable under all four combinations of year and emissions scenario (Table A1, Annex 1 and Table A3, Annex 3): *Afrotyphlops usambaricus, Lygodactylus conradti, L. gravis, Proscelotes eggeli, Prosymna ornatissima, Scelotes uluguruensis, Typhlacontias kataviensis, Urocotyledon wolterstorffi* and *Xyelodontophis uluguruensis*. Among them, three (*L. gravis, P. eggeli* and *X. uluguruensis*, see photos in Panel 1) have protected area coverage less than 20%.

4 Discussion

4.1 Major threats to Tanzanian reptiles

Agriculture poses an important and increasing threat to Tanzania's reptiles. Demand for arable lands is high (Newmark, 2002) and is projected to increase (Rosegrant et al., 2005) as a consequence of Tanzania's rapid population growth, low productivity of traditional agricultural practices and predominantly rain-fed production (MAFAP, 2013).

Farmland covers a large proportion of the Eastern Arc region, which contains forests and montane grasslands that are the most biologically diverse areas for reptiles in Tanzania. The Eastern Arc region has lost over 75% of its forest cover to agriculture (Hall et al., 2009) and now also supports a high human population density mostly reliant on subsistence agriculture (Platts et al., 2011).

The Eastern Arc region is also highly vulnerable to logging, and other wood uses, particularly due to its relative proximity to the rapidly expanding city of Dar es Salaam, and the associated increasing pressures on forest resources (Ahrends et al., 2010; Schaafsma et al., 2014).

The development of softwood plantations in Tanzania's montane grasslands poses threats to

doi:10.1016/j.biocon.2016.04.008

grassland-specialised endemics such as the Udzungwa long-tailed seps (*Tetradactylus udzungwensis*) (Endangered). Similar pressures are likely to threaten the Southern Highlands grassland lizard and the Ukinga mountain skink (*Trachylepis brauni*) (Vulnerable) in the future. Softwood plantations may expand in the grasslands around the existing Sao Hill plantation (Ngaga, 2011).

Tanzania is one of the four major chameleon-exporting countries in Africa (others being Madagascar, Togo and Kenya), accounting for 15% of the individuals and 38 species being exported and recorded by import countries between 1977 and 2001 (Carpenter et al., 2004). The latest official CITES trade records indicate that a few hundred specimens were legally traded in 2014 (although significant illegal trade is suspected). Anderson (2014) argued that the absence of leaf chameleons (*Rhampholeon* species) on CITES regulations has led to unsustainable harvesting and export of species from this group, for example *Rhampholeon spinosus* (Endangered). Trade is also a major threat to Tanzania's marine turtles, tortoises and pythons. Turtles and their products are traded internationally, supplying protein, leather, oil and ornamental objects to markets in Europe, America and Asia (Muir, 2005). Pythons are threatened by the emerging trade in skins (and, reputedly, meat).

4.2 Climate change impacts

The Red List is acknowledged to have shortcomings when considering climate change impacts (Akçakaya et al., 2006). Such shortcomings were the primary factor leading IUCN to develop and apply its trait based climate change vulnerability assessment approach.

The climate change vulnerability methodology used here employs arbitrary thresholds for continuous variables (e.g. 25% of species with greatest exposure to change in a given variable), rather than empirically tested thresholds of vulnerability. Our results therefore give an indication of which reptiles are likely to be most vulnerable to climate change within this group, but it is inappropriate to compare degrees of vulnerability between different taxonomic groups. Although this protocol broadly followed Foden et al. (2013), the use of reproductive output or generation length as a proxy for adaptive capacity may need further consideration. Other factors (e.g. body size) may provide better proxies for adaptive capacity.

When comparing spatial priorities for non-climate threatened reptiles with those for climate threatened reptiles, it is clear that these are not congruent. The main areas of non-climate threat are in the Eastern Arc and coastal forests in the east of the country, whereas the main areas of climate threat are in the northern coastal and north western margins of the country. This demonstrates how these two measures suggest different priority regions within a single country. Similar results were found at the

doi:10.1016/j.biocon.2016.04.008

Africa-wide scale by Garcia et al. (2014). Within Tanzania the current Red List assessment for reptiles primarily indicates regions suffering from the impacts of agricultural expansion, logging and the pet trade. These tend to be focused on the mountains and lowland forests in the east of the country. In comparison, the regions where climate change is projected to be more of a challenge are located mainly in the north and west of the country, in already drier regions where human use is less of an issue. As climate vulnerability assessments are, however, missing for chameleons, it is possible that the vulnerability of some mountain regions for reptiles has been underestimated in this paper.

4.3 Key areas for the conservation of Tanzanian reptiles

It might be expected that the cooler and wetter mountain regions would be less favourable to ectothermic reptiles, when compared with warmer lowlands. However, this is not the case and Tanzania shows broadly the same patterns of richness for reptiles as for other vertebrate groups (Fig. 2; Rovero et al., 2014), though less so for mammals. In particular, the Eastern Arc emerges as by far the most important region of the country for reptiles, as it is for other vertebrate groups. This may be a product of allopatric speciation and/or a high diversity of available niches (Szabo et al., 2009; Belmaker and Jetz, 2011), but may also be the result of more intense collecting efforts in the Eastern Arc, as previously demonstrated by the relationship between funding for biodiversity surveys and plant and vertebrate biodiversity measures (Ahrends et al., 2011; Rovero et al., 2014).

Our analysis shows that although most priority areas for reptiles in Tanzania such as the Eastern Arc region are already legally protected within reserves under various categories, especially Forest Reserves under the Tanzania Forest Service, gaps still exist when comparing the protected area coverage with globally threatened and climate change vulnerable species' distribution ranges. Furthermore, some of these reserves are, in reality, poorly funded relative to, for example National Parks (Green et al., 2012) and suffer considerable encroachment, degradation and deforestation (Ahrends et al., 2010; Pfeifer et al., 2012). This means that in order to ensure the long term conservation of reptiles in Tanzania, improved management of some reserves and in some cases the reconsideration of the reserves' range is critical.

4.4 Gaps in knowledge

As with most other regions, the distribution of Tanzania's reptiles is imperfectly known, with new species being regularly described (e.g. Menegon et al., 2011; Rovero et al., 2014). The rate of new reptile descriptions in Africa shows little indication of reaching a plateau (Menegon et al., 2015), and species numbers have increased by 65% in the last 26 years (Branch unpubl. obs.). Within Tanzania it

doi:10.1016/j.biocon.2016.04.008

is likely that the number of discovered reptile species, and hence their inferred patterns of richness and endemism, to some extent follow the intensity of collecting efforts and the availability of funding used on field surveys (Rovero et al., 2014). Elsewhere in Africa, new discoveries are often in reptile groups associated with rocky and xeric habitats (Branch, 2014). In Tanzania such habitats remain particularly poorly surveyed, despite a number of studies (e.g. Broadley, 2006; Bauer and Menegon, 2006) indicating that they contain hidden diversity. For instance, the biodiversity wealth of Eastern Arc Mountains is well known due to the extensive scientific focus it has obtained, but the Southern Highlands, to the south of Eastern Arc Mountains, divided by the Makambako gap, remains poorly known and has stronger affinities to the Eastern Arc than was previously acknowledged (Menegon et al., 2015).

The findings presented by this paper, around the distribution patterns of species richness, globally threatened species and climate change vulnerable species and the gaps existing in current protected area network, provide valuable information for policy makers, national and international conservation communities. We believe the results will help improve Tanzania's conservation action plans and investment strategies that contribute to closing knowledge-gaps on reptiles and other biodiversity.

5 Acknowledgements

We thank the Norwegian Government (Project Number TAN-09/049) through their Embassy in Dar es Salaam (Tanzania) for funding that has contributed to the development of the Red Listing of Tanzanian reptiles and their climate change vulnerability. The WWF Tanzania Country Programme Office is thanked for their efforts in managing the project that provided funding for this paper. Rob Marchant, Phil Platts, Claudia Capitani and Neil Burgess also thank the Ministry for Foreign Affairs, Finland, for funding support through the Climate Change Impacts on Ecosystem Services and Food Security in Eastern Africa (CHIESA) project.

6 Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.biocon.2016.04.008.

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Table 1. Number of Tanzanian reptile species with available distribution maps that were assessed for Red List status and/or climate change vulnerability.

Sources of species data	Number of species with available distribution maps	Number of species included in Red List Assessment	Number of species included in Climate change Vulnerability Assessment
Bagamoyo Workshop, January 2014, Tanzania	269[1]	276[2]	274[3]
Additional species (predominantly Chameleons)	10	45	Not assessed
Total	**279**	**321**	**274**

Notes:

[1]Of all species, 273 had available distribution maps, but the full distributions of four species were uncertain at the time of analysis, and so their distribution maps were excluded: *Causus bilineatus, Congolacerta vauereselli, Gonionotophis unicolor* (now *Gonionotophis chanleri* following Lanza and Broadley, 2014) and *Hemidactylus modestus.*

[2] Of the 280 species considered at the Bagamoyo workshop, four were omitted: *Agama persimilis* and *Telescopus dhara,* due to their first records from Tanzania being new reports; *Lygodactylus gutturalis* and *Megatyphlops mucroso* (now *Afrotyphlops* following Hedges *et al.,* 2014) were omitted due to errors regarding their countries of occurrence at the time of data collection.

[3] Trait data were collected only for species considered at the Bagamoyo workshop, of which, in addition to the four species omitted from Red List assessment, a further two species were excluded from the climate change vulnerability assessment: *Python sebae* was omitted from the assessment process due to human error; *Lycophidion pembanum* was only ever known from historical records and was therefore not considered in this study. See Table 2 for more detail on the number of species not assessed for climate change vulnerability.

doi:10.1016/j.biocon.2016.04.008

Table 2. Taxonomic table summarising reptile species considered in this paper. For each species family, numbers of total species, genera, endemic species, as well as numbers of species that are Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), Not Evaluated (NE) and climate change-vulnerable are included. 'N/A' means the species' Red List status was not set at the time of analysis.

Family	Total species	Genera	Endemic	CR	EN	VU	NT	LC	DD	N/A	NE	CC Vulnerable	Not assessed for CC vulnerability
AGAMIDAE	9	2	3	0	0	1	0	8	0	0	0	0	1
AMPHISBAENIDAE	10	4	7	0	0	0	0	2	8	0	0	6	
ATRACTASPIDIDAE	17	6	1	0	0	1	0	16	0	0	0	7	
BOIDAE	1	1	0	0	0	0	0	1	0	0	0	0	
CHAMAELEONIDAE	39	5	24	1	9	1	4	24	0	0	0	0	39
COLUBRIDAE	36	15	3	0	1	1	1	33	0	0	0	4	1
CORDYLIDAE	6	3	1	0	0	0	0	5	1	0	0	3	
CROCODYLIDAE	2	2	0	1	0	0	0	1	0	0	0	0	2
ELAPIDAE	14	4	0	0	0	1	0	13	0	0	0	2	1
EUBLEPHARIDAE	1	1	0	0	0	0	0	1	0	0	0	1	
GEKKONIDAE	36	8	15	1	0	5	2	20	8	0	0	16	1
GERRHOSAURIDAE	5	3	1	0	1	0	0	4	0	0	0	0	
GRAYIIDAE	2	1	0	0	0	0	0	2	0	0	0	0	
LACERTIDAE	15	8	1	0	0	0	1	12	1	0	1	9	
LAMPROPHIIDAE	14	3	2	0	0	0	0	11	3	0	0	0	1
LEPTOTYPHLOPIDAE	11	2	2	0	0	0	0	6	3	2	0	8	
NATRICIDAE	3	1	1	0	0	0	0	3	0	0	0	1	
PROSYMNIDAE	6	1	2	1	0	1	0	4	0	0	0	4	
PSAMMOPHIIDAE	18	5	0	0	0	0	0	17	1	0	0	0	
PSEUDASPIDIDAE	1	1	0	0	0	0	0	1	0	0	0	0	
PSEUDOXYRHOPHIIDAE	3	2	2	0	0	2	0	1	0	0	0	0	
PYTHONIDAE	2	1	0	0	0	0	1	1	0	0	0	0	1
SCINCIDAE	38	14	13	0	4	2	0	24	6	1	1	17	
TYPHLOPIDAE	16	4	9	0	2	2	0	7	4	1	0	8	
VARANIDAE	2	1	0	0	0	0	0	2	0	0	0	0	
VIPERIDAE	14	4	3	1	0	3	1	9	0	0	0	0	
TOTAL	**321**	**102**	**90**	**5**	**17**	**20**	**10**	**228**	**35**	**4**	**2**	**86**	**47**

doi:10.1016/j.biocon.2016.04.008

doi:10.1016/j.biocon.2016.04.008

Table 3. Major threats and threat-types (using IUCN's Red List classification scheme) known to be affecting reptile species in Tanzania. Note: Threat type 'climate change and severe weather' should not be compared to the trait-based climate change vulnerability assessment which aims to identify species that are not yet impacted to a degree that can be used in Red List assessment.

Threat category	Threat types within each category	Number of reptile species affected
Agriculture and aquaculture	Small-holder farming	38
	Small-holder grazing, ranching or farming	6
	Agro-industry farming	6
	Shifting agriculture	5
	Agro-industry plantations	5
	Small-holder plantations	1
	Agro-industry grazing, ranching or farming	1
Residential and commercial development	Housing and urban areas	8
	Commercial and industrial areas	3
Biological resource use	Logging and wood harvesting (unintentional effects)	17
	Hunting and trapping (intentional use)	14
	Intentional use: species is the target	11
	Hunting and trapping (persecution/control)	11
	Unintentional effects: subsistence/small scale harvesting	6
	Intentional use: subsistence/small scale harvesting	1
Climate change and severe weather	Habitat shifting and alteration	2
	Temperature extremes	1
	Droughts	1
	Increase in fire frequency/intensity	1
Invasive and other problematic species, genes and diseases	Problematic native species/diseases	2
	Invasive non-native/ alien species/ diseases	1
Human intrusions and disturbance	Recreational activities	1
Pollution	Herbicides and pesticides	3
	Domestic and urban waste water (type unknown)	1

doi:10.1016/j.biocon.2016.04.008

Threat category	Threat types within each category	Number of reptile species affected
	Oil spills	1
	Soil erosion, sedimentation	1
Energy production and mining	Mining and quarrying	4
	Oil and gas drilling	1
Natural system modifications	Dams (size unknown)	3
	Increase in fire frequency/intensity	3
	Other ecosystem modifications	1

doi:10.1016/j.biocon.2016.04.008

Table 4. Summary of the number and proportion of species being poorly protected in terms of low protected area coverage (Tier 1 and Tier 2) and the number and proportion of species being assessed as vulnerable within each of the two categories, according to Red List assessments (threatened or Data Deficient species) and climate change vulnerability assessments for 2041-2070 and 2071-2100 using RCP 4.5 and RCP 8.5. 'CC' – Climate Change; 'PA' – Protected Area

Total	**No. of species with valid maps**	**No. and % of poorly protected species among species with valid maps**	**No. and % of species assessed as climate change-vulnerable within each of the two 'poorly protected species' categories**					
			Red List Data Deficient	Red List Threatened	CC (2041-2070, RCP 4.5)	CC (2041-2070, RCP 8.5)	CC (2071-2100, RCP 4.5)	CC (2071-2100, RCP 8.5)
90 Tanzanian endemic species	**66**	< 10% PA Coverage **19** species	14 (74%)	0	15 (79%)	17 (89%)	18 (95%)	18 (95%)
		>= 10% and <20% PA Coverage **13** species	2 (15%)	7 (54%)	6 (46%)	9 (69%)	9 (69%)	9 (69%)
		Total: 32 (48%)	**16 (50%)**	**7 (22%)**	**21 (66%)**	**26 (81%)**	**27 (84%)**	**27 (84%)**
321 All assessed species	**279**	< 10% PA Coverage **54** species	18 (33%)	0	29 (54%)	34 (63%)	36 (67%)	36 (67%)
		>= 10% and <20% PA Coverage **62** species	2 (3%)	8 (13%)	25 (40%)	34 (55%)	34 (55%)	34 (55%)
		Total: 116 (42%)	**20 (17%)**	**8 (7%)**	**54 (47%)**	**68 (59%)**	**70 (60%)**	**70 (60%)**

doi:10.1016/j.biocon.2016.04.008

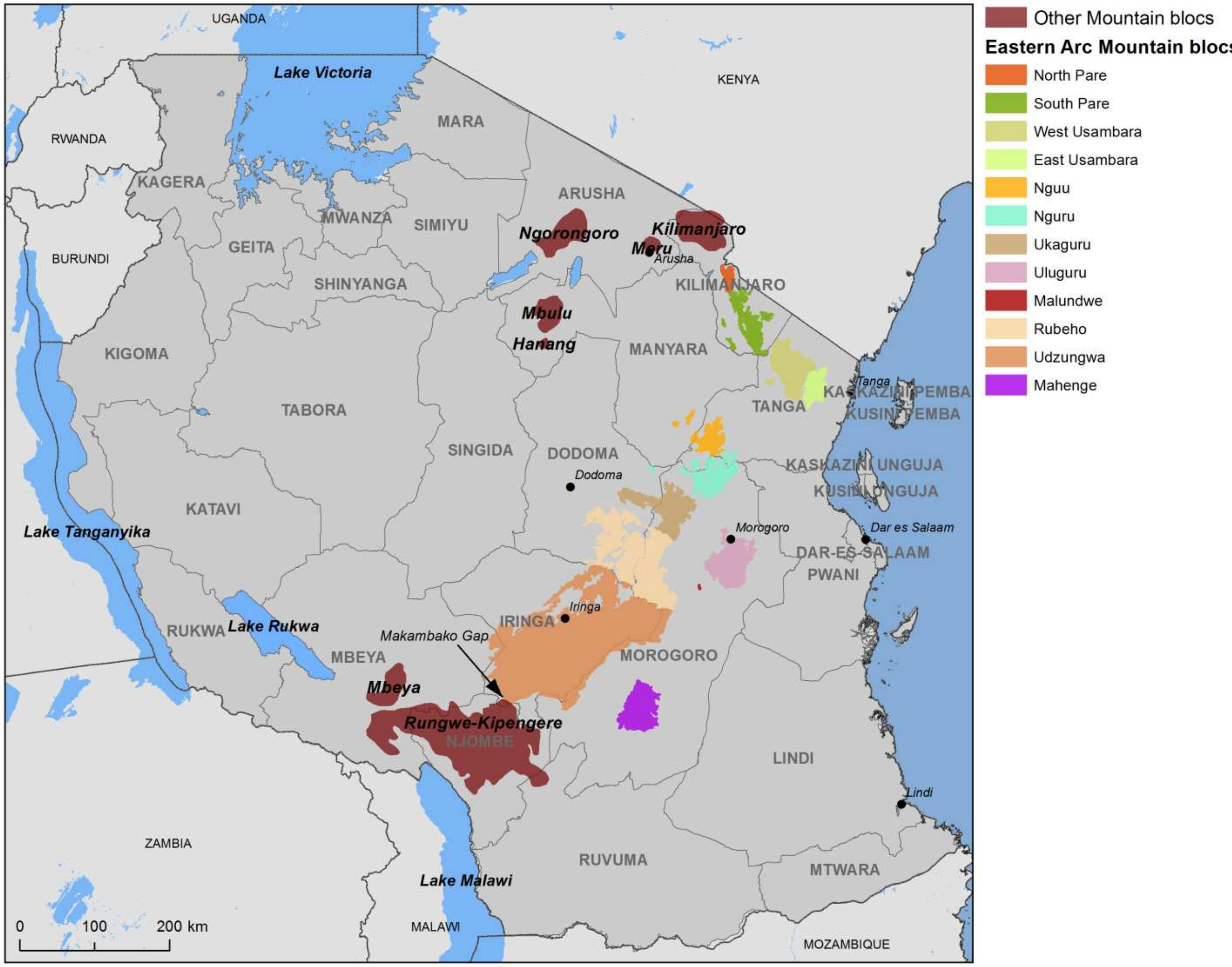

Figure 1. General map: regions, major lakes, mountain blocs and cities of Tanzania.

doi:10.1016/j.biocon.2016.04.008

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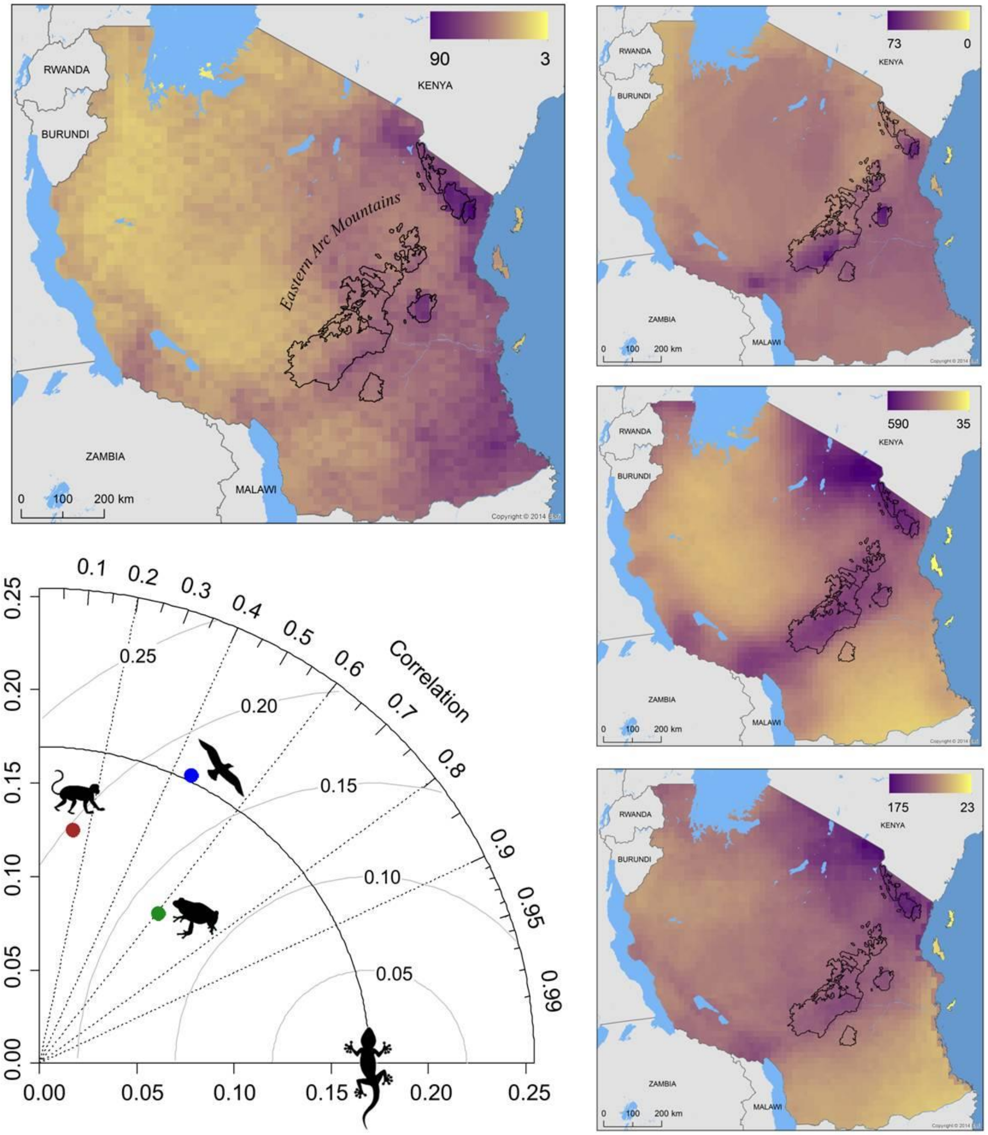
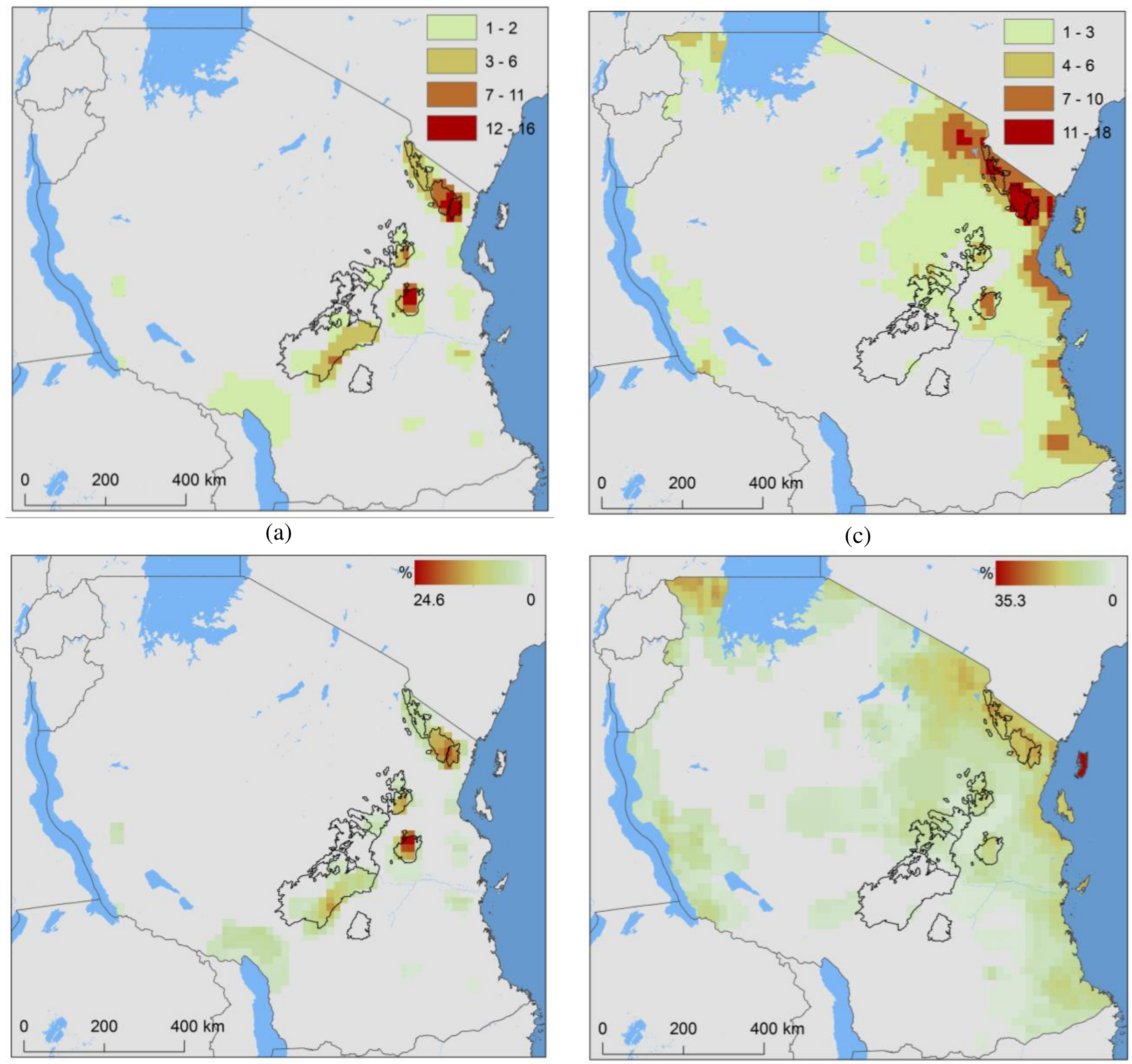
(a)
(b)
(c)
(d)
(e)



doi:10.1016/j.biocon.2016.04.008

Figure 2. Overall distribution pattern of reptile species richness (a) in Tanzania, in comparison with the richness patterns of amphibians (b), birds (c) and mammals (d). Normalising richness in each group to the interval [0, 1], Taylor diagram (e) shows standard deviations (sd, y-axis) compared with reptiles (gecko on the x-axis), as well as Pearson correlations (r, following straight lines from the origin) and centred root-mean-squared differences (rms, radial distances from gecko) between reptile richness and richness in other groups. For example, reptile richness is most highly correlated with amphibians ($r = 0.61$, $rms = 0.14$), while the variance is most similar to birds ($sd \approx 0.17$).

doi:10.1016/j.biocon.2016.04.008



doi:10.1016/j.biocon.2016.04.008

Figure 3. Relative richness of globally threatened (a, b) and climate change-vulnerable (c, d) reptiles in Tanzania. Top (a, c) and bottom (b, d) rows show, respectively, numbers and percentages (of the total number present) of species in these groups, per 10 arc-minute grid cell. Threatened species were assessed as Vulnerable, Endangered or Critically Endangered according to the IUCN Red List guidelines. Climate change vulnerability was determined using trait-based measures of sensitivity and adaptability, combined with climate change exposure by 2041-2070, under emissions pathway RCP4.5 and using optimistic assumptions for all unknown data values. Note that maps represent differing total numbers of species, as described in Table 1. Also note that the chameleons were not assessed for climate change vulnerability.

doi:10.1016/j.biocon.2016.04.008

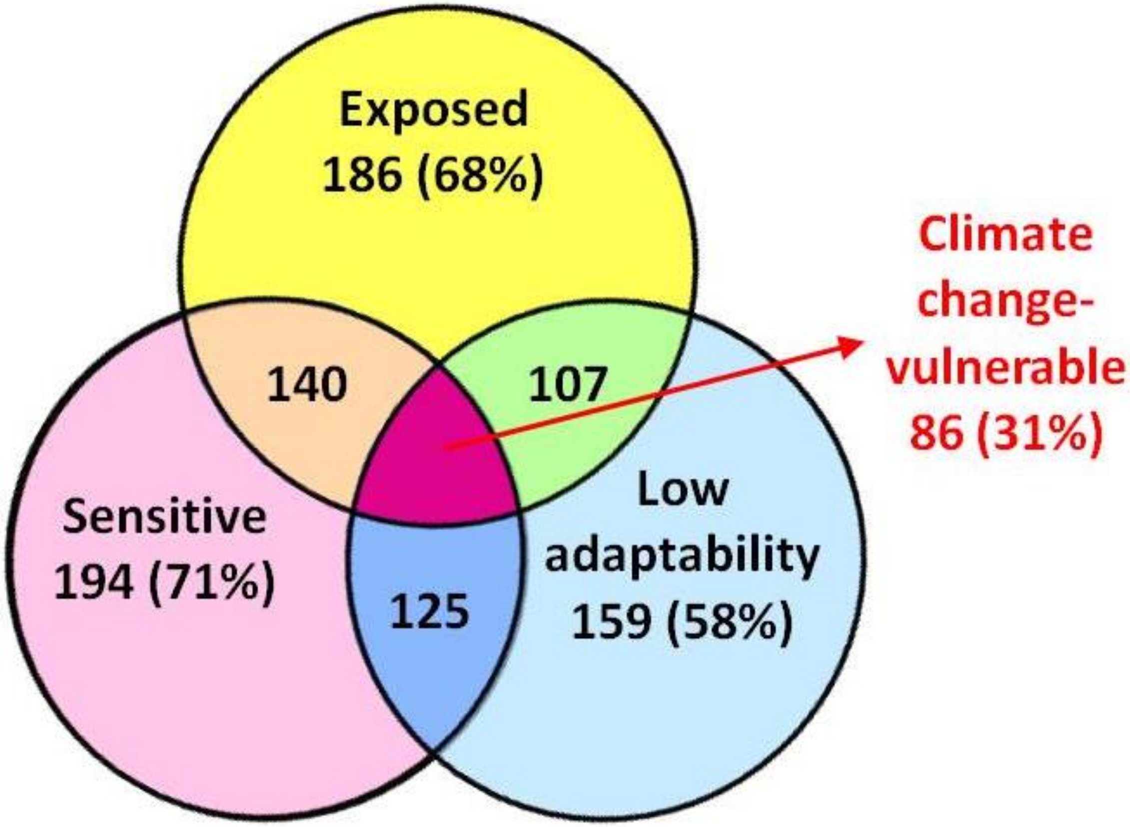


Figure 4. Numbers and percentages of the 274 species considered for the climate change vulnerability assessments falling into each of the three framework dimensions. Measures of exposure use climate projections to 2041-2070 under RCP4.5, and all dimensions treat unknown data points optimistically (i.e. assuming that are not negatively impacting the species).

doi:10.1016/j.biocon.2016.04.008

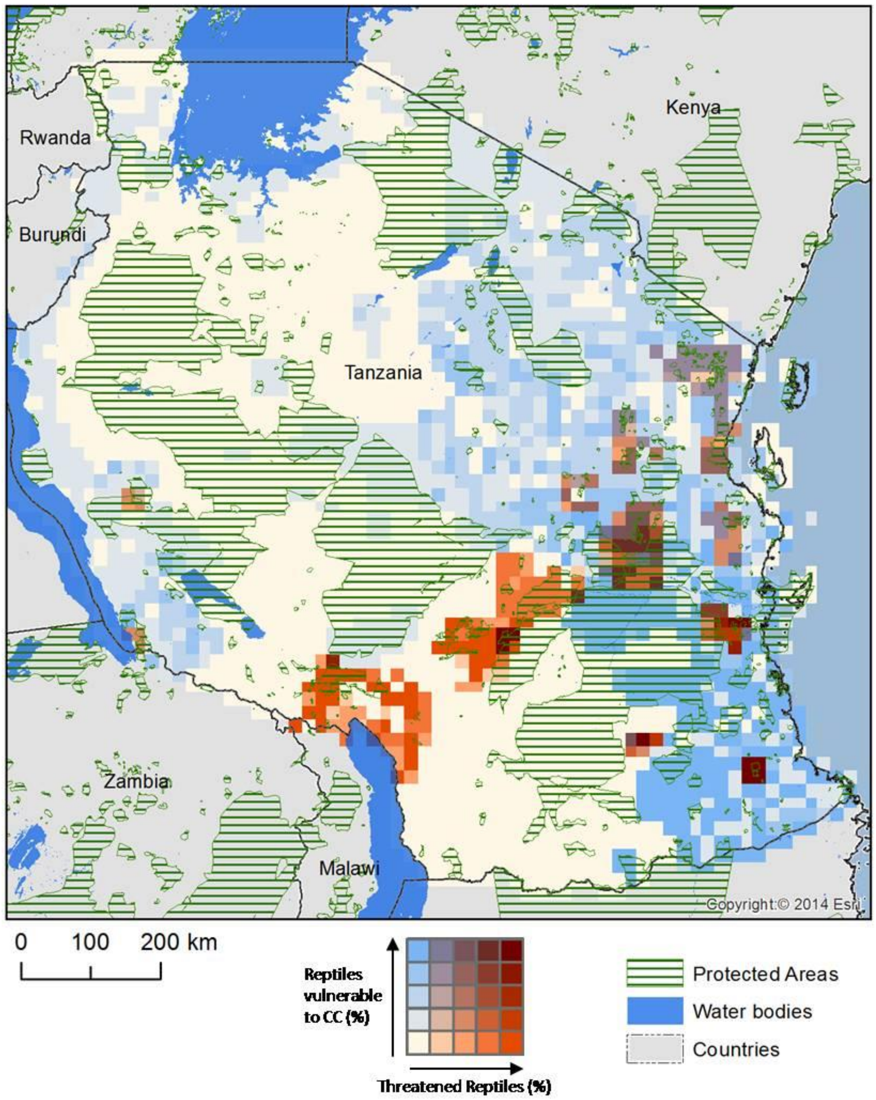


Figure 5. Current protected area network (WDPA; IUCN and UNEP-WCMC, 2014) in Tanzania overlaid on a bivariate map of climate change-vulnerable and globally threatened reptile species. Key gaps in protection of such species are: areas around the north of Lake Malawi, large areas of the Eastern Arc Mountains only partly covered by a scatter of protected areas as well as some small patches (southern Lindi and southern Liwale) in the south-eastern part of the country. CC = Climate Change.

doi:10.1016/j.biocon.2016.04.008

(a)

(b)

Panel 1. Based on all assessments in this paper, we highlighted three species that are globally threatened, endemic to Tanzania, and climate change-vulnerable under all four combinations of year and emissions scenario and poorly protected (protected area coverage of 14-20%): *Lygodactylus gravis* (a), *Xyelodontophis uluguruensis* (b), and *Proscelotes eggeli* (no photo of *P. eggeli* was available to the authors).

doi:10.1016/j.biocon.2016.04.008