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# 1 **Tanzania's Reptile Biodiversity: Distribution, Threats and Climate Change** 2 **Vulnerability**

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35

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37

**38 Abstract**

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

55

**56 1 Introduction**

57

58 Tanzania (Fig. 1) is characterised by a diverse range of landscapes and habitats, from mangroves  
59 through diverse savannah and forest habitats to alpine grasslands (Burgess et al., 2004). Some regions,  
60 for example the Eastern Arc Mountains, are thought to have acted as both refuges and areas of  
61 speciation during climatic cycles (Fjeldså and Lovett, 1997; Tolley et al., 2011). Tanzania's central  
62 arid region is regarded as an important element of Africa's 'Arid Corridor', facilitating faunal  
63 movements between the Namib in the south and Horn of African in the north (Bobe, 2006; Broadley,  
64 2006). However, there is no documentation of vertebrate biodiversity patterns at the Tanzanian  
65 national scale, with studies focused on more local biodiversity centres (e.g. Eastern Arc: Rovero et al.,  
66 2014; Coastal Regions: Burgess and Clarke, 2000), or at regional (e.g. African: Brooks et al., 2001;  
67 Burgess et al., 2004; Platts et al., 2014) or global scales (Pimmet al., 2014). As Tanzania is party to  
68 many global conventions, in particular the Convention of Biological Diversity, the lack of appropriate  
69 data on biodiversity patterns and threats hinders the development of National Biodiversity Strategies  
70 and Actions Plans, and other national policy instruments.

71

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

73 accepted framework for assessing the types and severity of threats to the survival of individual species  
74 (IUCN Standards and Petitions Subcommittee, 2014). Species distribution maps compiled during the  
75 Red Listing process, using primary data and expert knowledge, represent a species' known global  
76 range. In addition, the Red List system also gathers data of threats to species, which is being  
77 augmented to explicitly consider the threats from climate change (Carr et al., 2013; Foden et al.,  
78 2013). This development addresses some of the limitations of the Red List (Akçakaya  
79 et al., 2006) and acknowledges that climate change poses an increasingly significant threat to species.

80

81 Reptiles occur throughout Tanzania, with the exception of areas above the snowline (Spawls et al.,  
82 2002). Some reptile species have very small, restricted ranges and rely upon highly-specific  
83 environmental conditions, such as rainfall and temperature regimes and/or specific habitats in order to  
84 undergo particular life-history events (e.g. Zani and Rollyson, 2011; Weatherhead et al., 2012).  
85 Others, such as viviparous reptiles need to balance thermal budgets between normal daily activities  
86 and reproductive demands. As such, reptiles are particularly sensitive to changes in insolation  
87 (Sinervo et al., 2008) and may be especially vulnerable to climate change (Whitfield Gibbons et al.,  
88 2000).

89

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

97

98 In this paper we present new and existing reptile data for Tanzania to show: a) species richness; b)  
99 richness of threatened species; and c) richness of species considered vulnerable to climate change.

100 Reptile distribution patterns are compared with those for birds, mammals and amphibians to  
101 determine if biodiversity patterns are congruent between vertebrate groups. Gaps within Tanzania's  
102 protected area network are identified by evaluating the extent of reptile range overlap with protected  
103 areas. We also present knowledge-gaps that need to be filled for more effective conservation practices  
104 in the future. Our analyses are targeted at policy-makers and planners, and aim to facilitate the  
105 consideration of biodiversity in planning and conservation decision making and the better  
106 understanding of future protection requirements.

107

108

109

## 110 **2 Data and Methodology**

111

### 112 **2.1 Species data and the Red List assessment process**

113

114 Species data came from two sources: i) an IUCN Red Listing Workshop in Bagamoyo, Tanzania  
115 (January 2014); and ii) published IUCN Red List assessments. Nine expert herpetologists (from the  
116 author list: CM; IS; JCh; JB; KH; PM; PW; SS; WB) attended the 2014 workshop where they  
117 completed the standard IUCN Red Listing process (IUCN Standards and Petitions Subcommittee,  
118 2014; IUCN, 2015) and also provided climate change vulnerability-related trait information (see  
119 Section 2.2). Prior to this workshop a total of 37 Tanzanian reptile species (excluding marine species)  
120 had been assessed for the IUCN Red List, although many were considered in need of updating.

121

122 The preliminary list of Tanzanian reptile species was derived from Spawls et al. (2002) and Menegon  
123 et al. (2008). This was cross referenced against field guides and atlases from other regions of Africa  
124 that share species with Tanzania (Southern Africa — Branch, 1998; West Africa — Trape et al.,  
125 2012a; Trape and Mané, 2006a; Cameroon — Chirio and LeBreton, 2007; Ethiopia — Largen and  
126 Spawls, 2010; Somalia — Lanza, 1990), and the Reptile Database (<http://www.reptile-database.org>)  
127 (Uetz and Hošek, 2013) was used to identify more recent descriptions. Inconsistencies between these  
128 lists were referred to experts for resolution. A number of major taxonomic studies and revisions have  
129 been undertaken since Spawls et al. (2002); key references consulted in this regard include Broadley  
130 and Wallach (2007, 2009: *Typhlopidae*); Adalsteinsson et al. (2009: *Leptotyphlopidae*); Trape et al.  
131 (2006: *Atractaspis*); Trape and Mané (2006b); Trape et al. (2012b) (*Dasypeltis*) and Kelly et al.  
132 (2008: *Psammophiidae*). One species, *Agama dodomae*, was included prior to its formal description  
133 following discussions with the describing author, as the description was due to be published prior to  
134 finalisation of the Red List results (Wagner, 2014). Species lists for chameleons, pythons and vipers  
135 were confirmed by the relevant IUCN SSC Specialist Groups.

136

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

140

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

145

146 To investigate the spatial congruence of reptile species richness and richness in other vertebrate  
147 groups, we obtained range maps for 188 amphibian, 356 mammal, and 1046 bird species, all recorded  
148 as occurring in Tanzania, from the IUCN Red List of Threatened Species (IUCN, 2015)  
149 (<http://www.iucnredlist.org/technical-documents/spatial-data>). For consistency with reptile richness,  
150 individual species maps were gridded at 10 arc-minute resolutions and summed over species within a  
151 group. We summarised spatial congruence between group richness using a Taylor diagram (Taylor,  
152 2001), which normalises richness in each group to the interval [0,1], and then plots a comparison of  
153 standard deviations, Pearson correlations and centred root-mean-squared differences between reptile  
154 richness and richness in other groups (Taylor, 2001). Due to potentially confounding effects of spatial  
155 autocorrelation, values of Pearson's *r* were checked against those derived from spatially random  
156 samples of 30 cells (1% of the total), such that the mean distance (km) between adjacent sampling  
157 points was  $101 \pm 10$  s.d. over 10,000 repetitions.

158

## 159 **2.2 Climate change vulnerability**

160

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

166

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

179

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

181 relevant climatic variables on species' distribution maps (Table A2.1, Annex 2). Climate grids for  
182 1950–2000 were from WorldClim (Hijmans et al., 2005). For consistency with climate change  
183 vulnerability assessments of other groups (amphibians, birds and mammals), we used mean values to  
184 resample WorldClim grids from 30" (c. 1 km) to 10' (c. 19 km). For future climate (2041– 2070 and  
185 2071–2100) we used data from AFRICLIM v1 (Platts et al., 2015), which provides high-resolution  
186 ensemble means derived in a two-step downscaling procedure from eight CMIP5 General Circulation  
187 Models (GCMs): CanESM2, CNRM-CM5, EC-EARTH, GFDL-ESM2G, HadGEM2-ES, MIROC5,  
188 MPI-ESM-LR and NorESM1-M. First, each GCM was dynamically downscaled to a resolution of  
189 0.44° (c. 50 km) using the SMHI-RCA4 regional climate model, in order to better capture climatic  
190 processes operating at sub-GCM scales. Second, regional outputs were empirically downscaled (bias-  
191 corrected) against the WorldClim baselines (Platts et al., 2015). Two representative concentration  
192 pathways (RCPs) of the IPCC-AR5 were considered, characterising a stabilisation of radiative forcing  
193 shortly after 2100 (RCP4.5) or increasing greenhouse gas emissions over time (RCP 8.5) (van Vuuren  
194 et al., 2011).

195

196 Using these data, we calculated the projected changes in four variables: (i) absolute change in mean  
197 temperature; (ii) ratio of change in total precipitation; (iii) absolute change in temperature variability  
198 (calculated as the average absolute deviation from the mean); and (iv) ratio of change in precipitation  
199 variability (calculated in the same manner as iii). A species was designated as 'highly exposed' if its  
200 exposure with respect to any of these variables exceeded a given threshold. Following Foden et al.  
201 (2013) and other applications of the IUCN Climate Change Vulnerability Assessment Framework  
202 (e.g. Carr et al., 2013, 2014), thresholds were fixed across scenarios, at levels determined by the  
203 quartile of most severely exposed species under RCP4.5 (2041-2070).

204

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

213

### 214 **2.3 Protected area gap analysis**

215

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

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

222

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

227

### 228 **3 Results**

229

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

235

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

243

#### 244 **3.1 Diversity and distribution of threatened reptiles**

245

246 Forty-two (13%) reptile species are (provisionally, pending final review and publication) considered to  
247 be globally threatened with extinction (Vulnerable, Endangered or Critically Endangered), and 36  
248 (11%) have been assessed as Data Deficient (Table A1, Annex 1).

249

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

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

259  
 260 Our assessment of non-climatic threats to reptiles shows that ‘agriculture/ aquaculture’ and ‘biological  
 261 resource use’ present the most significant threats (Table 3). Within these broad classifications,  
 262 ‘smallholder farming’, ‘logging and wood harvesting’ and ‘hunting and trapping’ (both for  
 263 ‘intentional use’ and for ‘persecution/control’) are common threat types.

264  
 265 The international pet trade poses a threat to some restricted-range reptile species, including Tanzanian  
 266 endemics. In Tanzania, the majority of chameleon species are traded, often at unsustainable levels.  
 267 The turquoise dwarf gecko (*Lygodactylus williamsi*) (Critically Endangered) is currently collected at  
 268 unsustainable levels (Flecks et al., 2012). The pancake tortoise (*Malacochersus tornieri*) is also  
 269 threatened by the pet trade (Klemens and Moll, 1995; UNEP-WCMC, 2015). Savannah-endemic  
 270 species, such as *Agama dodomae*, are collected and traded in high and potentially unsustainable  
 271 numbers (Wagner, 2010).

272

273

### 274 **3.2 Diversity and distribution of climate change-vulnerable reptiles**

275

276 For the period 2041–2070, using climate projections based on the RCP4.5 emission pathway a total of  
 277 186 species (68%) were considered as ‘high’ and 87 species (32%) as ‘low’ in terms of their projected  
 278 exposure to climate change (Table A2.1, Annex 2). One species (b1%) was ‘unknown’, and this  
 279 remained across all combinations of time periods and emissions pathways. For the period 2071 to  
 280 2100, based on RCP 4.5 (but using the same thresholds determined for the above results), 270 species  
 281 (98.5%) were considered ‘high’ and three (1%) as ‘low’. Using RCP 8.5, for both time periods, and  
 282 again using the same thresholds, 273 species (> 99%) were considered ‘high’ and zero as ‘low’.

283

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

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

291

292 One hundred and fifty-nine species (58%) were assessed as possessing traits that make them poorly  
293 able to adapt to climate change (Table A2.3, Annex 2). Among these traits, a low intrinsic capacity to  
294 disperse (Trait A2) was the most common, present in 136 species (50%). Data for traits relating to a  
295 species' capacity to adapt to change in-situ through genetic micro-evolution (Traits A4 and A5) were  
296 missing in many cases: information on reproductive output (Trait A4) was unavailable for 240 species  
297 (88%), and information on species maximum longevity (a proxy for generation length (Trait A5)) was  
298 unavailable for 264 species (96%).

299

300 When combining the exposure, sensitivity and adaptive capacity components, 86 (31%) or 175 (64%)  
301 reptile species were considered vulnerable to climate change by 2041–2070, using climate projections  
302 based on the RCP4.5 emissions pathway, and an optimistic or pessimistic assumption of missing data  
303 values, respectively (Fig. 4; Table A3, Annex 3). These numbers increase to 125 (46%) (optimistic) or  
304 248 (90.5%) (pessimistic) under rising emissions (RCP 8.5), and to 122 (45%) (optimistic)/245 (89%)  
305 (pessimistic) or 125 (46%) (optimistic)/ 248 (90.5%) (pessimistic) by 2071–2100 for RCP 4.5 and  
306 RCP 8.5, respectively (Table A3, Annex 3).

307

308 Focusing on mid-century (2041–2070) under RCP 4.5, which we consider more immediately relevant  
309 to conservation, the highest concentrations and proportions of climate change-vulnerable reptile  
310 species (up to 18 species per grid cell) are found in the dry habitats of northern Tanga (Fig. 3c, d). A  
311 broad area with 10 to 13 climate change-vulnerable reptile species per grid cell is found in the  
312 northeastern (bordering Kenya) and eastern (coastal and inland) parts of Tanzania. There are also  
313 regions of importance in Kagera, Rukwa, Dodoma, Morogoro and the islands of Zanzibar, Pemba and  
314 Mafia. These trends, although not absolute numbers, are consistent across emissions pathways (RCP  
315 4.5 or RCP8.5) and time-spans (2041–2070 or 2071–2100), and under different assumptions for  
316 missing data values (Table A3, Annex 3). Note, however, that maps are only presented for the RCP  
317 4.5/2041–2070 combination). These areas are not congruent with areas highlighted previously as  
318 containing high numbers of threatened species, a point which is discussed later in this paper.

319

### 320 **3.3 Gaps in Tanzania's protected area network**

321

322 Of the assessed reptile species with available distribution maps, 116 (42%) have less than 20% of  
323 their Tanzanian ranges protected by the current protected area network (54 of these with <10%). Of  
324 the species with < 20% protected, eight are threatened, and 54 to 70 (or 47–60%) are vulnerable to

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

328

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

334

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

341

## 342 **4 Discussion**

343

### 344 **4.1 Major threats to Tanzanian reptiles**

345

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

350

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

355

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

359

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

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

365

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

376

#### 377 **4.2 Climate change impacts**

378

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

382

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

391

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

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

404

#### 405 **4.3 Key areas for the conservation of Tanzanian reptiles**

406

407 It might be expected that the cooler and wetter mountain regions would be less favourable to  
408 ectothermic reptiles, when compared with warmer lowlands. However, this is not the case and  
409 Tanzania shows broadly the same patterns of richness for reptiles as for other vertebrate groups (Fig.  
410 2; Rovero et al., 2014), though less so for mammals. In particular, the Eastern Arc emerges as by far  
411 the most important region of the country for reptiles, as it is for other vertebrate groups. This may be a  
412 product of allopatric speciation and/or a high diversity of available niches (Szabo et al., 2009;  
413 Belmaker and Jetz, 2011), but may also be the result of more intense collecting efforts in the Eastern  
414 Arc, as previously demonstrated by the relationship between funding for biodiversity surveys and  
415 plant and vertebrate biodiversity measures (Ahrends et al., 2011; Rovero et al., 2014).

416

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

426

#### 427 **4.4 Gaps in knowledge**

428

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

433 is likely that the number of discovered reptile species, and hence their inferred patterns of richness  
434 and endemism, to some extent follow the intensity of collecting efforts and the availability of funding  
435 used on field surveys (Rovero et al., 2014). Elsewhere in Africa, new discoveries are often in reptile  
436 groups associated with rocky and xeric habitats (Branch, 2014). In Tanzania such habitats remain  
437 particularly poorly surveyed, despite a number of studies (e.g. Broadley, 2006; Bauer and Menegon,  
438 2006) indicating that they contain hidden diversity. For instance, the biodiversity wealth of Eastern  
439 Arc Mountains is well known due to the extensive scientific focus it has obtained, but the Southern  
440 Highlands, to the south of Eastern Arc Mountains, divided by the Makambako gap, remains poorly  
441 known and has stronger affinities to the Eastern Arc than was previously acknowledged (Menegon et  
442 al., 2015).

443

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

449

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451

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459

## 460 **6 Appendix A. Supplementary data**

461

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

464

## 465 **7 References**

466

467 Adalsteinsson, S.A., Branch, W.R., Trapé, S., Vitt, L.J., Hedges, S.B., 2009. Molecular phylogeny,  
468 classification, and biogeography of snakes of the family Leptotyphlopidae (Reptilia, Squamata).

- 469 Zootaxa 2244, 1–50.
- 470 Ahrends, A., Burgess, N.D., Milledge, S.H., Bulling, M.T., Fisher, B., et al., 2010. Predictable waves  
471 of sequential forest degradation and biodiversity loss spreading from an African city. Proceedings of  
472 the National Academy of Sciences of the United States of America. 107, pp. 14556–14561.
- 473 Ahrends, A., Burgess, N.D., Gereau, R.E., Marchant, R., Bulling, M.T., et al., 2011. Funding begets  
474 biodiversity. *Divers. Distrib.* 17, 191–200.
- 475 Akçakaya, H.R., Butchart, S.H.M., Mace, G.M., Stuart, S.N., Hilton-Taylor, C., 2006. Use and misuse  
476 of the IUCN Red List Criteria in projecting climate change impacts on biodiversity. *Glob. Chang.*  
477 *Biol.* 12, 2037–2043.
- 478 Anderson, C.V., 2014. The trade status of *Rhampholeon spinosus*. Chameleons! Online EZine, June  
479 2014 <http://www.chameleonnews.com/14JunAndersonSpinosus.html>.
- 480 Bauer, A.M., Menegon, M., 2006. A new species of prehensile-tailed gecko, *Urocotyledon*  
481 (Squamata: Ekkonidae), from the Udzungwa Mountains, Tanzania. *Afr. J. Herpetol.* 55 (1), 13–22.
- 482 Belmaker, J., Jetz, W., 2011. Cross-scale variation in species richness—environment associations.  
483 *Glob. Ecol. Biogeogr.* 20, 464–474.
- 484 Bobe, R., 2006. The evolution of arid ecosystems in eastern Africa. *J. Arid Environ.* 66, 564–584.
- 485 Branch, W.R., 1998. Field Guide to Snakes and Other Reptiles of Southern Africa. Struik Publishers,  
486 Cape Town.
- 487 Branch, W.R., 2014. Reptiles of South Africa, Lesotho and Swaziland: Conservation status, diversity,  
488 endemism, hotspots and threats. In: Bates, M.F., Branch, W.R., Bauer, A.M., Burger, M., Marais, J.,  
489 et al. (Eds.), Atlas and Red Data Book of the Reptiles of South Africa, Lesotho and Swaziland.  
490 Suricata 1, South African National Biodiversity Institute, Pretoria, pp. 22–50.
- 491 Broadley, D.G., 2006. A new species of *Typhlacontias* (Reptilia: Scincidae: Feylininae) from western  
492 Tanzania. *Proceedings of the California Academy of Science* 57 (20), 557–560.
- 493 Broadley, D.G., Wallach, V., 2007. A review of East and Central African species of *Letheobia Cope*,  
494 revived from the synonymy of *Rhinotyphlops Fitzinger*, with descriptions of five new species.  
495 *Zootaxa* 1515, 31–68.
- 496 Broadley, D.G., Wallach, V., 2009. A review of the eastern and southern African blind snakes  
497 (Serpentes: Typhlopidae), excluding *Letheobia Cope*, with the description of two new genera and a

- 498 new species. *Zootaxa* 2255, 1–100.
- 499 Brooks, T., Balmford, A., Burgess, N., Fjeldså, J., Hansen, L.A., et al., 2001. Towards a blueprint for  
500 conservation in Africa. *Bioscience* 51, 613–624.
- 501 Burgess, N., D'Amico Hales, J., Underwood, E., Dinerstein, E., Olson, D., et al., 2004. Terrestrial  
502 Ecoregions of Africa and Madagascar: A Continental Assessment. Island Press, Washington DC, pp.  
503 1–501.
- 504 Burgess, N.D., Clarke, G.P. (Eds.), 2000. The Coastal Forests of Eastern Africa. IUCN Forest  
505 Conservation Programme, Gland and Cambridge, pp. 1–435.
- 506 Carpenter, A.I., Marcus Rowcliffe, J., Watkinson, A.R., 2004. The dynamics of the global trade in  
507 chameleons. *Biol. Conserv.* 120, 291–301.
- 508 Carr, J.A., Outhwaite, W.E., Goodman, G.L., Oldfield, T.E.E., Foden, W.B., 2013. Occasional Paper  
509 of the Species Survival Commission No. 48. Available at:  
510 <https://portals.iucn.org/library/efiles/edocs/SSC-OP-048.pdf>.
- 511 Carr, J.A., Hughes, A.F., Foden, W.B., 2014. A Climate Change Vulnerability Assessment of West  
512 African Species. UNEP-WCMC Technical Report. Available at [http://www.parcc-web.org/parcc-](http://www.parcc-web.org/parcc-project/documents/2014/04/carr-et-al-2014-a-climatechangevulnerability-assessment-of-west-african-species-main-report-unesp-wcmctechnical-report.pdf)  
513 [project/documents/2014/04/carr-et-al-2014-a-climatechangevulnerability-assessment-of-west-african-](http://www.parcc-web.org/parcc-project/documents/2014/04/carr-et-al-2014-a-climatechangevulnerability-assessment-of-west-african-species-main-report-unesp-wcmctechnical-report.pdf)  
514 [species-main-report-unesp-wcmctechnical-report.pdf](http://www.parcc-web.org/parcc-project/documents/2014/04/carr-et-al-2014-a-climatechangevulnerability-assessment-of-west-african-species-main-report-unesp-wcmctechnical-report.pdf).
- 515 Chirio, L., LeBreton, M., 2007. Atlas Des Reptiles Du Cameroun. IRD Editions, Paris.
- 516 Foden, W.B., Butchart, S.H.M., Stuart, S.N., Vié, J., Akçakaya, H.R., et al., 2013. Identifying the  
517 world's most climate change-vulnerable species: a systematic trait-based assessment of all birds,  
518 amphibians and corals. *PLoS One* 8, e65427.
- 519 Fjeldså, J., Lovett, J.C., 1997. Biodiversity and environmental stability. *Biodivers. Conserv.* 6, 315–  
520 323.
- 521 Flecks, M., Weinsheimer, F., Böhme, W., Chenga, J., Lötters, S., et al., 2012. Watching extinction  
522 happen: the dramatic population decline of the critically endangered Tanzanian turquoise dwarf  
523 gecko, *Lygodactylus williamsi*. *Salamandra* 48 (1), 12–20.
- 524 Garcia, R.A., Araújo, M.B., Burgess, N.D., Foden, W.B., Gutsche, A., et al., 2014. Matching species  
525 traits to projected threats and opportunities from climate change. *J. Biogeogr.*  
526 <http://dx.doi.org/10.1111/jbi.12257>.

- 527 Green, J.H.M., Burgess, N.D., Green, R.E., Madoffe, S.S., Munishi, P.K.T., et al., 2012. Estimating  
528 management costs of protected areas: a novel approach from the Eastern Arc Mountains, Tanzania.  
529 Biol. Conserv. 150, 5–14.
- 530 Hall, J., Burgess, N.D., Lovett, J., Mbilinyi, B., Gereau, R.E., 2009. Conservation implications of  
531 deforestation across an elevational gradient in the Eastern Arc Mountains, Tanzania. Biol. Conserv.  
532 142, 2510–2521.
- 533 Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high resolution  
534 interpolated climate surfaces for global land areas. Int. J. Climatol. 25, 1965–1978.
- 535 IUCN and UNEP-WCMC (2014). The World Database on Protected Areas (WDPA) [Online],  
536 [October 2014]. Cambridge, UK: UNEP-WCMC. Available at: [www.protectedplanet.net](http://www.protectedplanet.net).
- 537 IUCN, 2015. IUCN Spatial Data Resources. [http://www.iucnredlist.org/technicaldocuments/red-list-](http://www.iucnredlist.org/technicaldocuments/red-list-training/iucnspatialresources)  
538 [training/iucnspatialresources](http://www.iucnredlist.org/technicaldocuments/red-list-training/iucnspatialresources) Accessed August 2015.
- 539 IUCN Standards and Petitions Subcommittee, 2014. Guidelines for Using the IUCN Red List  
540 Categories and Criteria. Version 11. Prepared by the Standards and Petitions Subcommittee.  
541 Downloadable from [http://www.iucnredlist.org/ documents/RedListGuidelines.pdf](http://www.iucnredlist.org/documents/RedListGuidelines.pdf).
- 542 Joppa, L.N., Alexander, P., 2009. High and far: biases in the location of protected areas. PLoS One 4  
543 (12).
- 544 Kelly, C.M.R., Barker, N.P., Villet, N.H., Broadley, D.G., Branch, W.R., 2008. The snake family  
545 *Psammophiidae* (Reptilia: Serpentes): phylogenetics and species delimitation in the African sand  
546 snakes (*Psammophis* Boie, 1825) and allied genera. Mol. Phylogenet. Evol. 47, 1045–1060.
- 547 Klemens, M.W., Moll, D., 1995. An assessment of the effects of commercial exploitation on the  
548 pancake tortoise, *Malacochersus tornieri*, in Tanzania. Chelonian Conservation and Biology 1, 197–  
549 206.
- 550 Largen, M., Spawls, S., 2010. The Amphibians and Reptiles of Ethiopia and Eritrea. Edition  
551 Chimaira, Frankfurt am Main, Germany.
- 552 Lanza, B., 1990. Amphibians and reptiles of the Somali Democratic Republic: checklist and  
553 biogeography. Biogeographica 407–465.
- 554 Lanza, B., Broadley, D.G., 2014. A review of the genus *Gonionotophis* in northeastern Africa  
555 (Squamata: Lamprophiidae). Acta Herpetologica 9 (1), 89–97.

- 556 MAFAP, 2013. Review of Food and Agricultural Policies in the United Republic of Tanzania.  
557 MAFAP Country Report Series. FAO, Rome, Italy 221 pp.
- 558 Menegon, M., Doggart, N., Owen, N., 2008. The Nguru Mountains of Tanzania, an outstanding  
559 hotspot of herpetofaunal diversity. *Acta Herpetologica* 3, 107–127.
- 560 Menegon, M., Davenport, T.R.B., Howell, K.M., 2011. Description of a new and critically  
561 endangered species of *Atheris* (Serpentes: Viperidae) from the southern highlands of Tanzania, with  
562 an overview of the country's tree viper fauna. *Zootaxa* 3120, 43–54.
- 563 Menegon, M., Loader, S.P., Davenports, T.R.B., Howell, K.M., Tilbury, C.R., et al., 2015. A new  
564 species of chameleon (Sauria: Chamaeleonidae: *Kinyongia*) highlights the biological affinities  
565 between the southern highlands and Eastern Arc Mountains of Tanzania. *Acta Herpetologica* 10 (2),  
566 111–120.
- 567 Muir, C., 2005. The Status of Marine Turtles in the United Republic of Tanzania, East Africa. Sea  
568 Sense (Tanzania Turtle and Dugong Conservation Programme).
- 569 Ngaga, Y.M., 2011. Forest plantations and woodlots in Tanzania. African forest forum working paper  
570 series 1 (16).
- 571 Newmark, W.D., 2002. Conserving Biodiversity in East African Forests: A Study of the Eastern Arc  
572 Mountains. Springer Science and Business Media, p. 197.
- 573 Pfeifer, M., Burgess, N.D., Swetnam, R.D., Platts, P.J., Willcock, S., et al., 2012. Protected areas:  
574 mixed success in conserving East Africa's evergreen forests. *PLoS One* 7 (6), e39337.  
575 <http://dx.doi.org/10.1371/journal.pone.0039337>.
- 576 Pimm, S.L., Jenkins, C.N., Abell, R., Brooks, T.M., Gittleman, J.L., et al., 2014. The biodiversity of  
577 species and their rates of extinction, distribution, and protection. *Science* 344 (6187).  
578 <http://dx.doi.org/10.1126/science.1246752>.
- 579 Platts, P.J., Burgess, N.D., Gereau, R.E., Lovett, J.C., Marshall, A.R., et al. (2011). Delimiting tropical  
580 mountain ecoregions for conservation. *Environ. Conserv.*, 38, 312–324.
- 581 Platts, P.J., Garcia, R.A., Hof, C., Foden, W., Hansen, L.A., et al., 2014. Conservation implications of  
582 omitting narrow-ranging taxa from species distribution models, now and in the future. *Divers. Distrib.*  
583 20, 1307–1320.
- 584 Platts, P.J., Omeny, P.A., Marchant, R., 2015. AFRICLIM: high-resolution climate projections for

- 585 ecological applications in Africa. *Afr. J. Ecol.* 53, 103–108.
- 586 Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., et al., 2004. Effectiveness  
587 of the global protected area network in representing species diversity. *Nature* 428 (6983), 640–643.
- 588 Rondinini, C., Stuart, S., Boitani, L., 2005. Habitat suitability models and the shortfall in conservation  
589 planning for African vertebrates. *Conserv. Biol.* 19 (5), 1488–1497.
- 590 Rosegrant, M.W., Cline, S.A., Li, W., Sulser, T.B., Valmonte-Santos, R.A., 2005. Looking Ahead:  
591 Long-Term Prospects for Africa's Agricultural Development and Food Security. 2020 Discussion  
592 Paper No. 41 International Food Policy Research Institute, Washington, D.C.
- 593 Rovero, F., Menegon, M., Fjeldså, J., Collett, L., Doggart, N., et al., 2014. Targeted vertebrate  
594 surveys enhance the faunal importance and improve explanatory models within the Eastern Arc  
595 Mountains of Kenya and Tanzania. *Divers. Distrib.* <http://dx.doi.org/10.1111/ddi.1224>.
- 596 Schaafsma, M., Burgess, N.D., Swetnam, R.D., Ngaga, Y.M., Turner, R.K., et al., 2014. Market  
597 signals of unsustainable and inequitable forest extraction: assessing the value of illegal timber trade in  
598 the Eastern Arc Mountains of Tanzania. *World Dev.* 62, 155–168.
- 599 Sinervo, B., Méndez-de-la-Cruz, F., Miles, D.B., Heulin, B., Bastiaans, E., et al., 2008. Erosion of  
600 lizard diversity by climate change and altered thermal niches. *Science* 328 (5980), 894–899.
- 601 Spawls, S., Howell, K., Drewes, R., Ashe, J., 2002. *A Field Guide to the Reptiles of East Africa.*  
602 Kenya, Tanzania, Rwanda and Burundi. Academic Press, London, UK.
- 603 Sritharan, S., Burgess, N.D., 2012. Protected area gap analysis of important bird areas in Tanzania.  
604 *Afr. J. Ecol.* 50 (1), 66–76.
- 605 Szabo, N.D., Algar, A.C., Kerr, J.T., 2009. Reconciling topographic and climatic effects on  
606 widespread and range-restricted species richness. *Glob. Ecol. Biogeogr.* 18, 735–744.
- 607 Taylor, K.E., 2001. Summarizing multiple aspects of model performance in a single diagram. *J.*  
608 *Geophys. Res.* 106, 7183–7192.
- 609 Tolley, K.A., Tilbury, C.R., Measey, G.J., Menegon, M., Branch, W.R., et al., 2011. Ancient forest  
610 fragmentation or recent radiation? Testing refugial speciation models in chameleons within an African  
611 biodiversity hotspot. *J. Biogeogr.* 38, 1748–1760.
- 612 Trape, J.-F., Mané, Y., 2006a. *Guide des serpents d'Afrique occidentale—savane et désert.* IRD  
613 Editions, Paris.

- 614 Trape, J.-F., Mané, Y., 2006b. Le genre *Dasypeltis* Wagler (Serpentes: Colubridae) en Afrique de  
615 l'Ouest: description de trois espèces et d'une sous-espèce nouvelles. *Bulletin of the Society of*  
616 *Herpetology of France* 119, 27–56.
- 617 Trape, S., Mediannikov, O., Trape, J.-F., 2012a. When colour patterns reflect phylogeography: new  
618 species of *Dasypeltis* (Serpentes: Colubridae: Boigini) from West Africa. *Comptes Rendus Biologies*  
619 335 (7), 488–501.
- 620 Trape, J.-F., Trape, S., Chirio, L., 2012b. *Lézards, crocodiles et tortues d'Afrique occidentale et du*  
621 *Sahara*. IRD Editions, Marseille.
- 622 Trape, J.-F., Mané, Y., Ineich, I., 2006. *Atractaspis microlepidota*, *A. micropholis* et *A. watsoni* en  
623 Afrique occidentale et centrale. *Bulletin de la Société Herpétologique de France* 2006 (119), 5–16.
- 624 Uetz, P. and Jirí Hošek (eds.), *The Reptile Database*, <http://www.reptile-database.org>, accessed  
625 October–November 2013.
- 626 UNEP-WCMC, 2015. Report on Standing Committee Recommendations to Suspend Trade That Were  
627 Made More Than Two Years Ago Through the Review of Significant Trade. UNEP-WCMC,  
628 Cambridge.
- 629 van Vuuren, D.P., Edmonds, J., Kainuma, M.L.T., Riahi, K., Thomson, A., et al., 2011.  
630 Representative concentration pathways: an overview. *Clim. Chang.* 109, 5–31.
- 631 Wagner, P., 2010. Diversity and distribution of African reptiles, with a special focus on agamid  
632 lizards (Unpublished PhD thesis) University of Bonn 374 p.
- 633 Wagner, P., 2014. A new cryptic species of the *Agama lionotus* complex from south of the Ngong  
634 Hills in Kenya. *Salamandra* 50 (4), 187–200.
- 635 Weatherhead, P.J., Sperry, J.H., Carfagno, G.L.F., Blouin-Demers, G., 2012. Latitudinal variation in  
636 thermal ecology of North American ratsnakes and its implications for the effect of climate warming  
637 on snakes. *J. Therm. Biol.* 37, 273–281.
- 638 Whitfield Gibbons, J., Scott, D.E., Ryan, T.J., Buhlmann, K.A., Tuberville, T.D., et al., 2000. The  
639 global decline of reptiles, déjà vu amphibians. *Bioscience* 50 (8), 653–666.
- 640 Zani, P.A., Rollyson, M., 2011. The effects of climate modes on growing-season length and timing of  
641 reproduction in the Pacific northwest as revealed by biophysical modeling of lizards. *Am. Midl. Nat.*  
642 165, 372–388.

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

645

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 <sup>1</sup>	276 <sup>2</sup>	274 <sup>3</sup>
Additional species (predominantly Chameleons)	10	45	Not assessed
<b>Total</b>	<b>279</b>	<b>321</b>	<b>274</b>

646

647 **Notes:**

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

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

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

662

663

**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	
<b>TOTAL</b>	<b>321</b>	<b>102</b>	<b>90</b>	<b>5</b>	<b>17</b>	<b>20</b>	<b>10</b>	<b>228</b>	<b>35</b>	<b>4</b>	<b>2</b>	<b>86</b>	<b>47</b>



**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
<b>Agriculture and aquaculture</b>	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
<b>Residential and commercial development</b>	Housing and urban areas	8
	Commercial and industrial areas	3
<b>Biological resource use</b>	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	
<b>Climate change and severe weather</b>	Habitat shifting and alteration	2
	Temperature extremes	1
	Droughts	1
	Increase in fire frequency/intensity	1
<b>Invasive and other problematic species, genes and diseases</b>	Problematic native species/diseases	2
	Invasive non-native/ alien species/ diseases	1
<b>Human intrusions and disturbance</b>	Recreational activities	1
<b>Pollution</b>	Herbicides and pesticides	3
	Domestic and urban waste water (type unknown)	1

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

**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	<u>&lt; 10% PA Coverage</u> 19 species	14 (74%)	0	15 (79%)	17 (89%)	18 (95%)	18 (95%)
		<u>&gt;= 10% and &lt;20% PA Coverage</u> 13 species	2 (15%)	7 (54%)	6 (46%)	9 (69%)	9 (69%)	9 (69%)
		<b>Total: 32 (48%)</b>	<b>16 (50%)</b>	<b>7 (22%)</b>	<b>21 (66%)</b>	<b>26 (81%)</b>	<b>27 (84%)</b>	<b>27 (84%)</b>
321 All assessed species	279	<u>&lt; 10% PA Coverage</u> 54 species	18 (33%)	0	29 (54%)	34 (63%)	36 (67%)	36 (67%)
		<u>&gt;= 10% and &lt;20% PA Coverage</u> 62 species	2 (3%)	8 (13%)	25 (40%)	34 (55%)	34 (55%)	34 (55%)
		<b>Total: 116 (42%)</b>	<b>20 (17%)</b>	<b>8 (7%)</b>	<b>54 (47%)</b>	<b>68 (59%)</b>	<b>70 (60%)</b>	<b>70 (60%)</b>

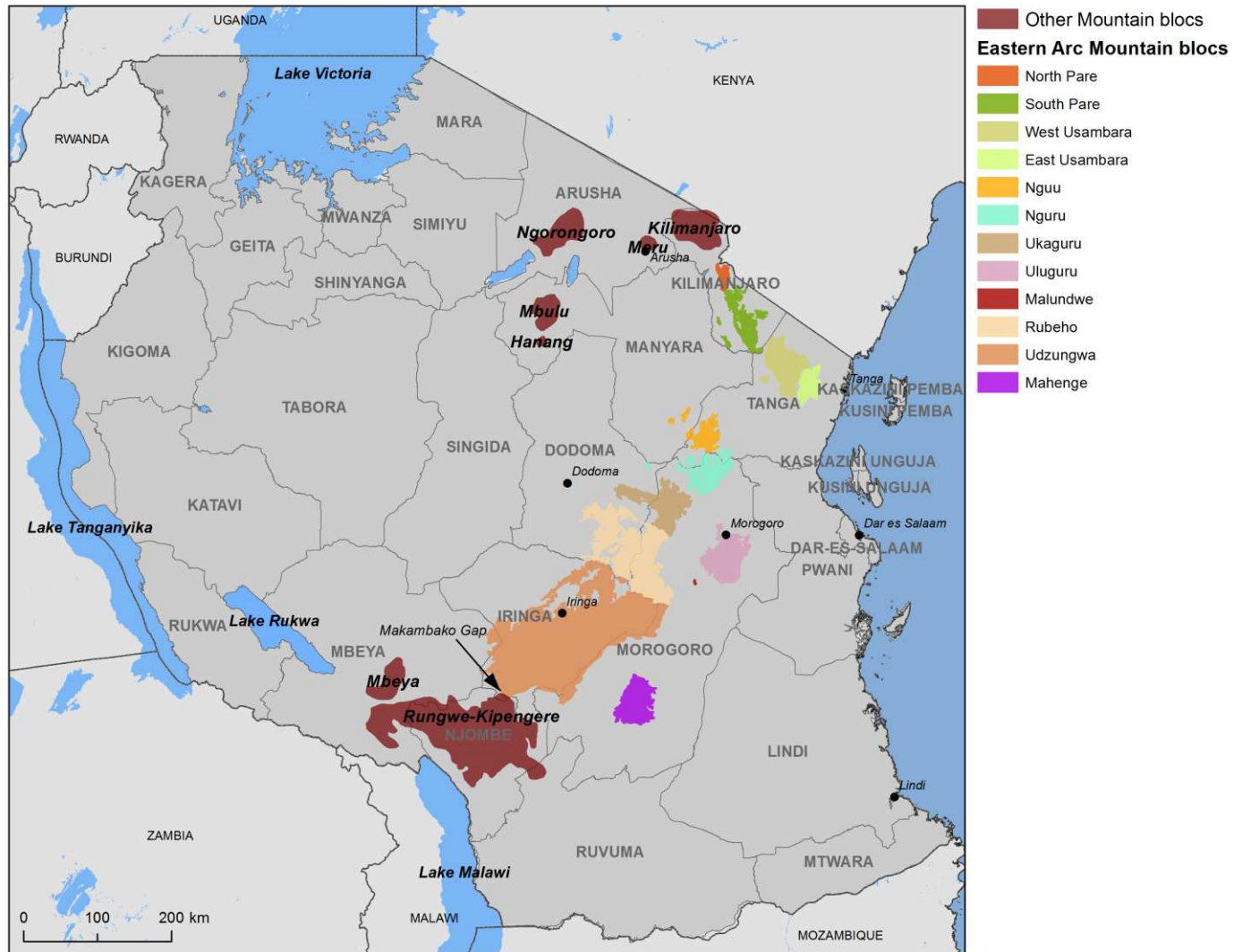


Figure 1. General map: regions, major lakes, mountain blocs and cities of Tanzania.

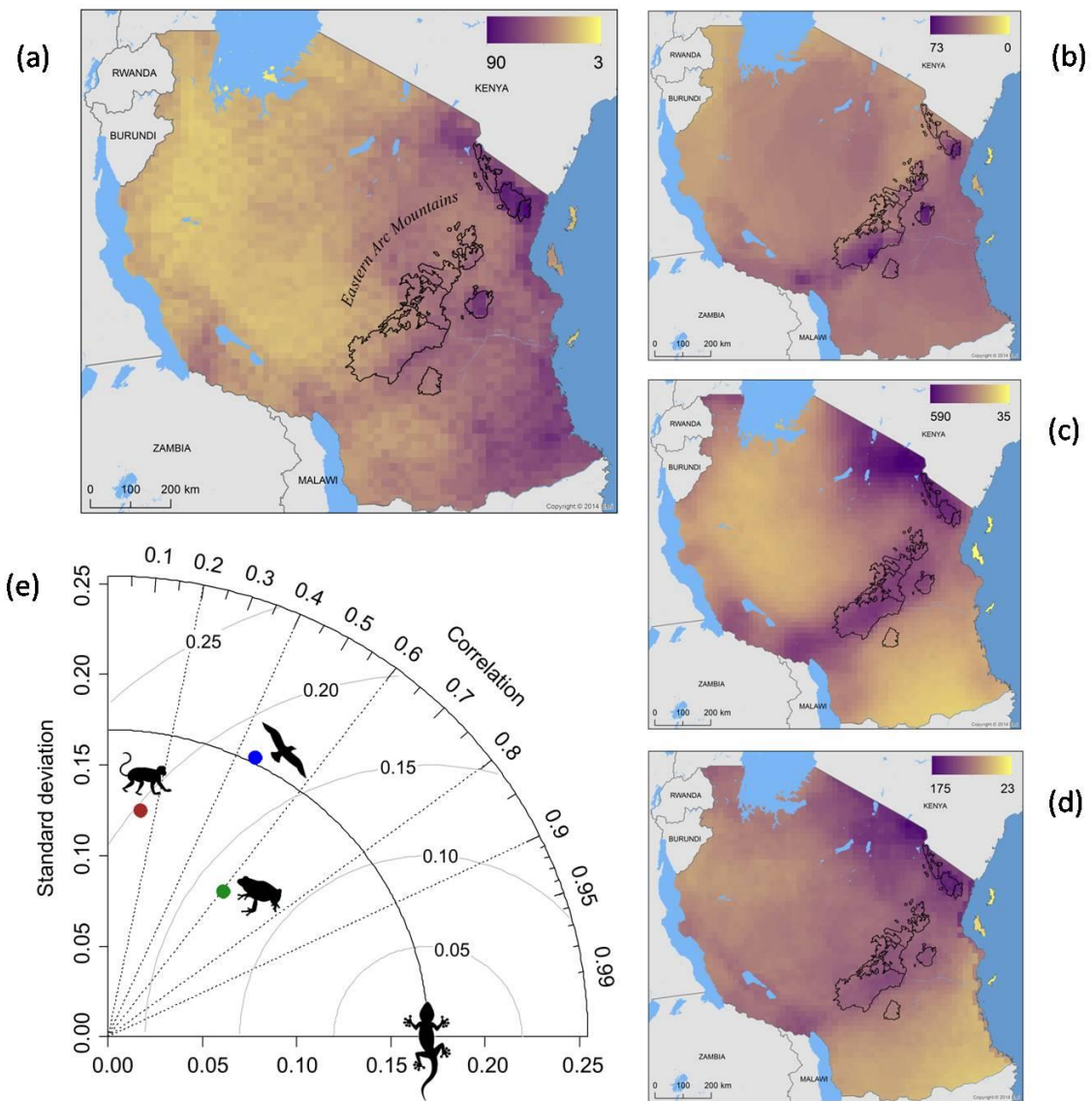
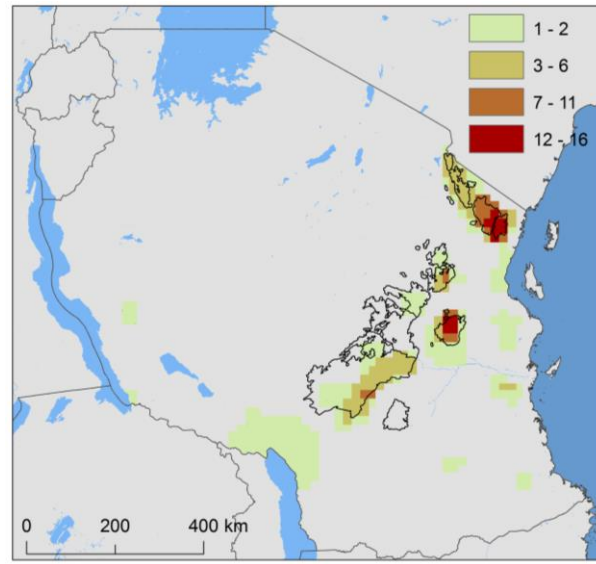
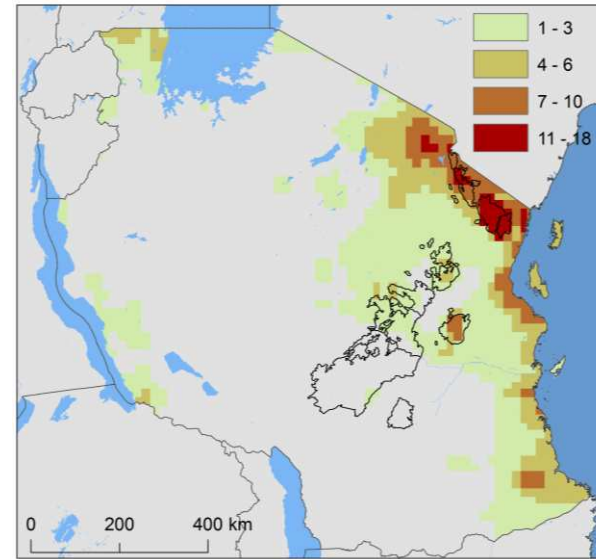


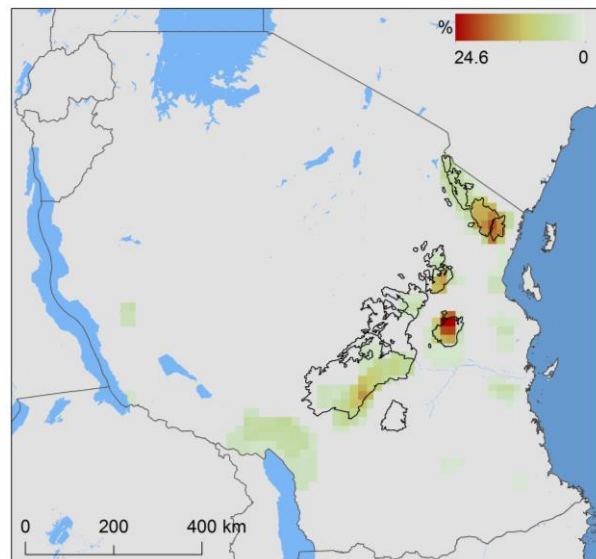
Figure 2. Overall distribution pattern of reptile species richness (a) in Tanzania, in comparison with the richness patterns of amphibians (b), birds (c) and mammals (d). Normalising richness in each group to the interval [0, 1], Taylor diagram (e) shows standard deviations (sd, y-axis) compared with 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 ( $r = 0.61$ ,  $\text{rms} = 0.14$ ), while the variance is most similar to birds ( $\text{sd} \approx 0.17$ ).



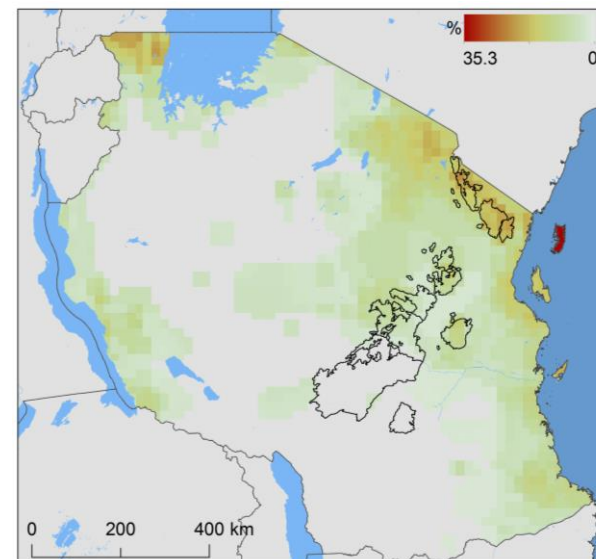
(a)



(c)



(b)



(d)

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.

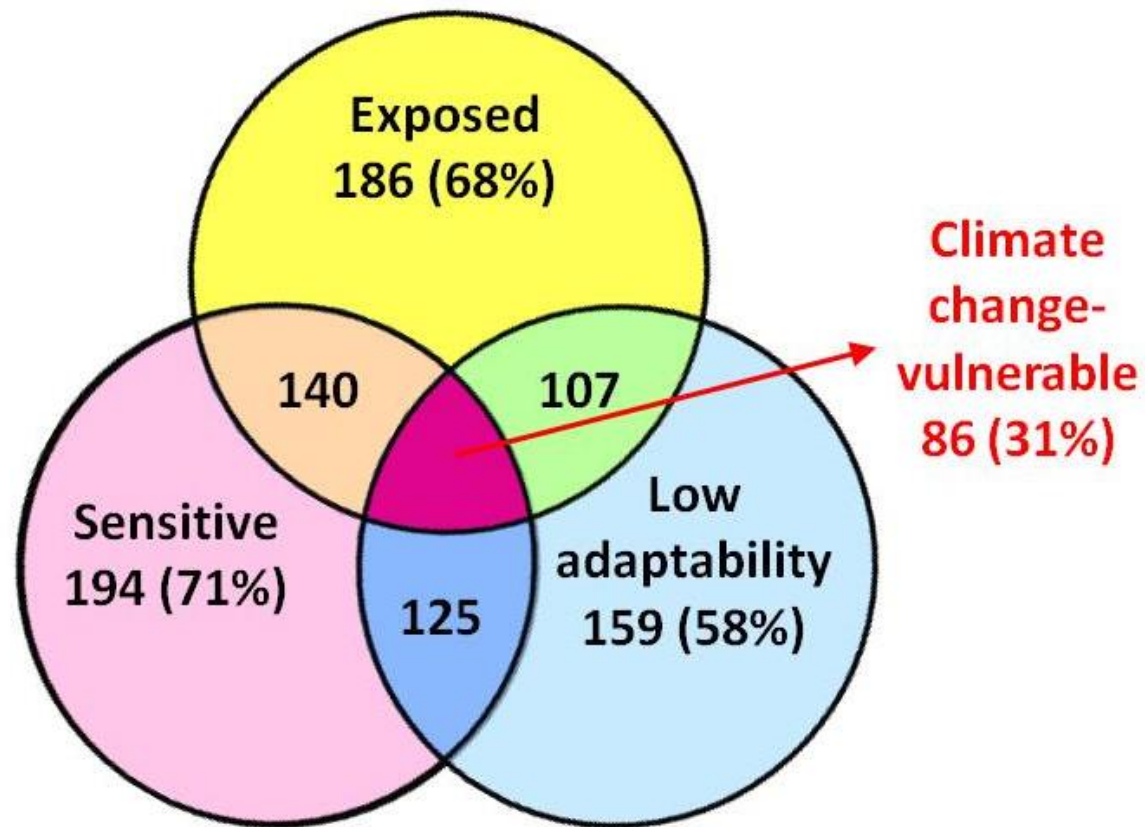


Figure 4. Numbers and percentages of the 274 species considered for the climate change vulnerability assessments falling into each of the three framework dimensions. Measures of exposure use climate projections to 2041-2070 under RCP4.5, and all dimensions treat unknown data points optimistically (i.e.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

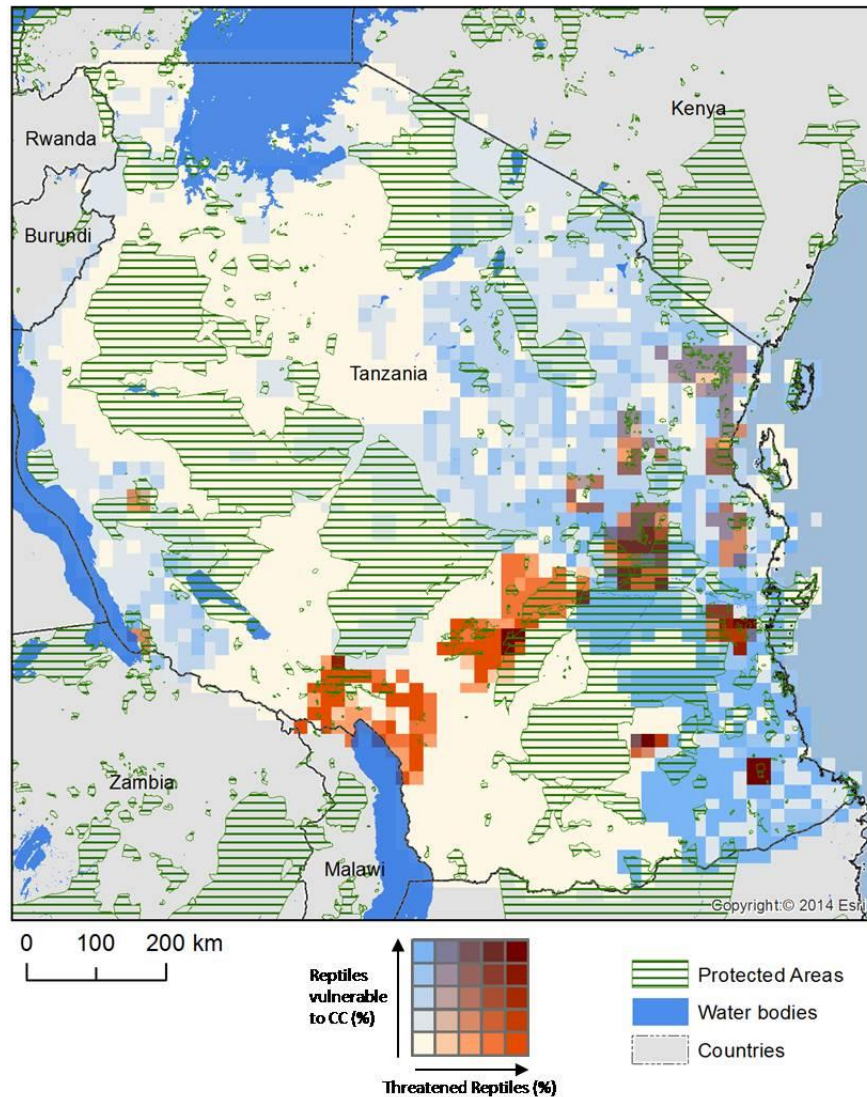


Figure 5. Current protected area network (WDPA; IUCN and UNEP-WCMC, 2014) in Tanzania overlaid on a bivariate map of climate change-vulnerable and globally threatened reptile species. Key gaps in protection of such species are: areas around the north of Lake Malawi, large areas of the Eastern Arc Mountains 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.



(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).