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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 ± 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
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464

465 **7 References**

466

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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 ¹ | 276 ² | 274 ³ |
| Additional species (predominantly Chameleons) | 10 | 45 | Not assessed |
| Total | 279 | 321 | 274 |

646

647 **Notes:**

648 ¹Of 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 ² 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 ³ 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 | |
| TOTAL | 321 | 102 | 90 | 5 | 17 | 20 | 10 | 228 | 35 | 4 | 2 | 86 | 47 |

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 |

| 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 |

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>< 10% PA Coverage</u> 19 species | 14 (74%) | 0 | 15 (79%) | 17 (89%) | 18 (95%) | 18 (95%) |
| | | <u>>= 10% and <20% PA Coverage</u> 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 | <u>< 10% PA Coverage</u> 54 species | 18 (33%) | 0 | 29 (54%) | 34 (63%) | 36 (67%) | 36 (67%) |
| | | <u>>= 10% and <20% PA Coverage</u> 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%) |

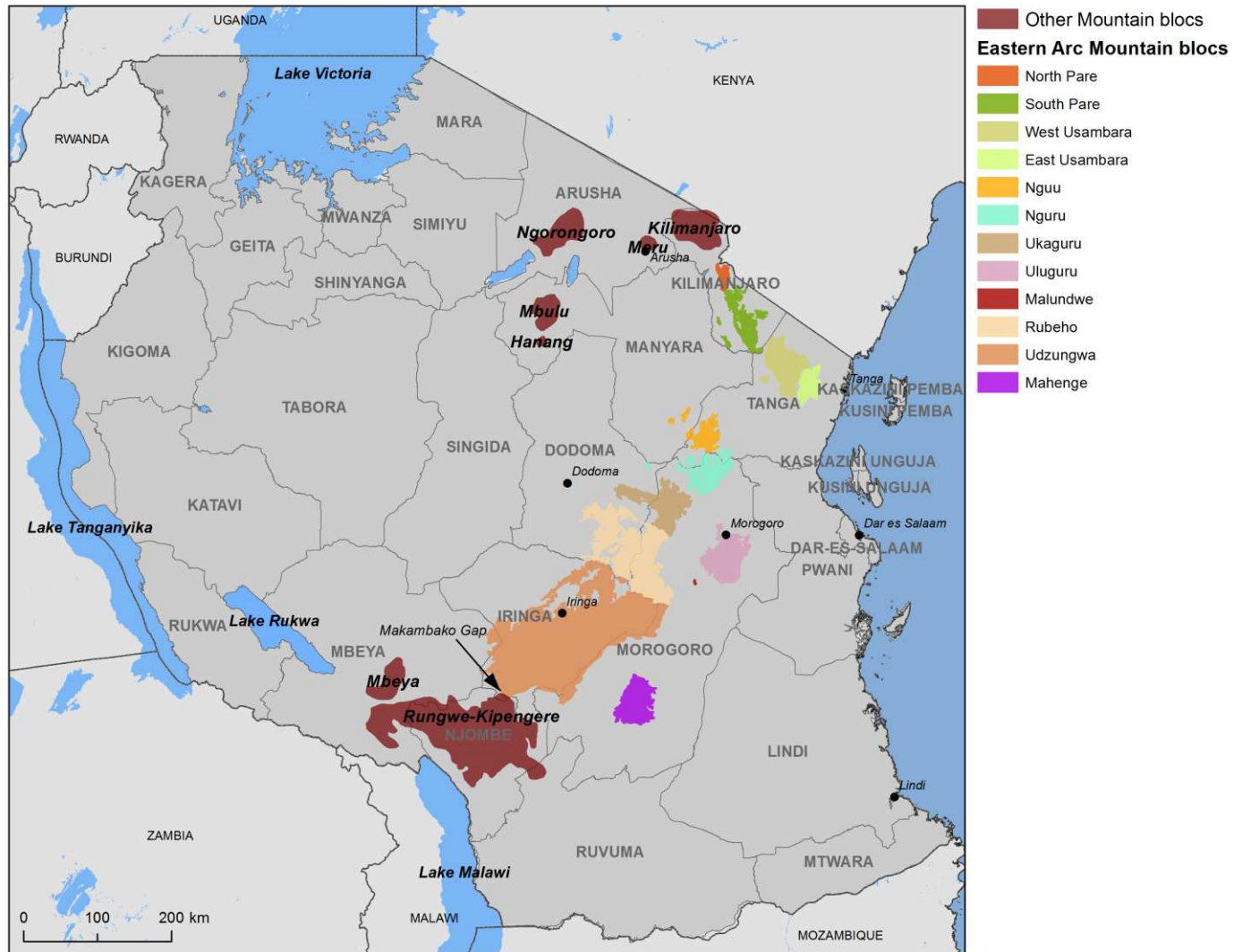


Figure 1. General map: regions, major lakes, mountain blocs and cities of Tanzania.

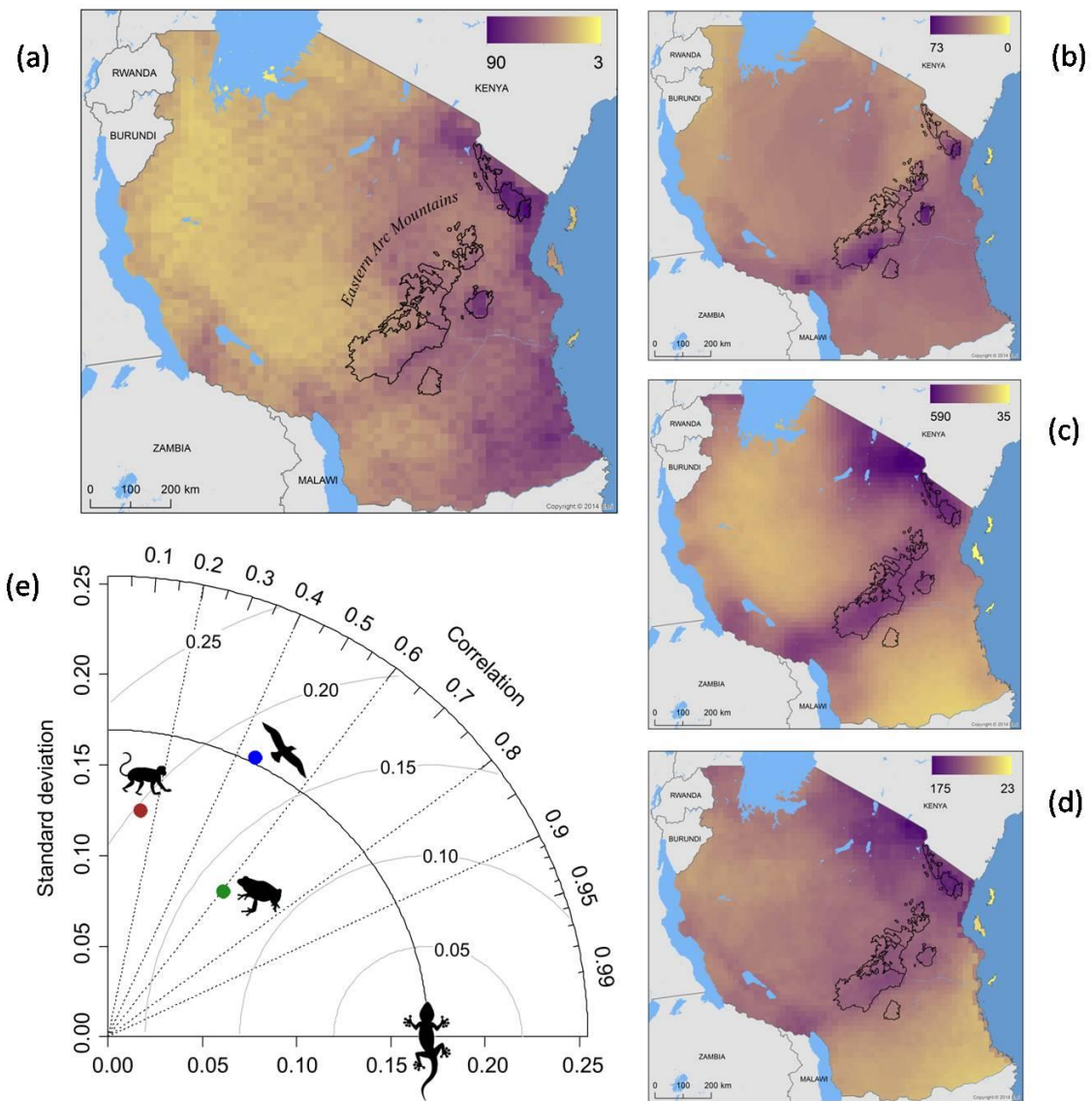
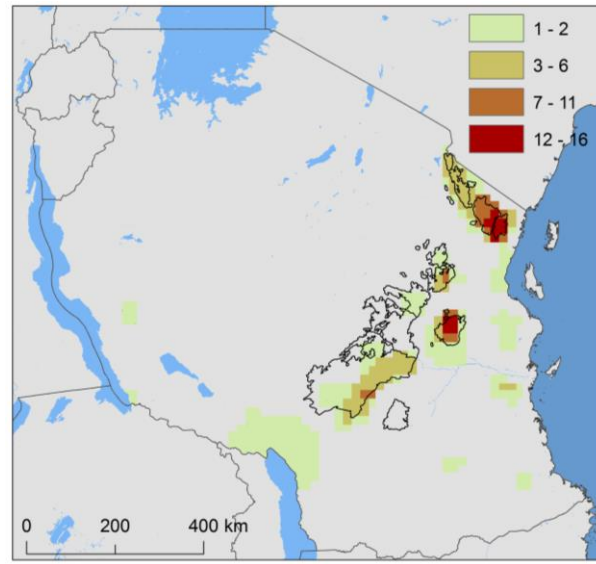
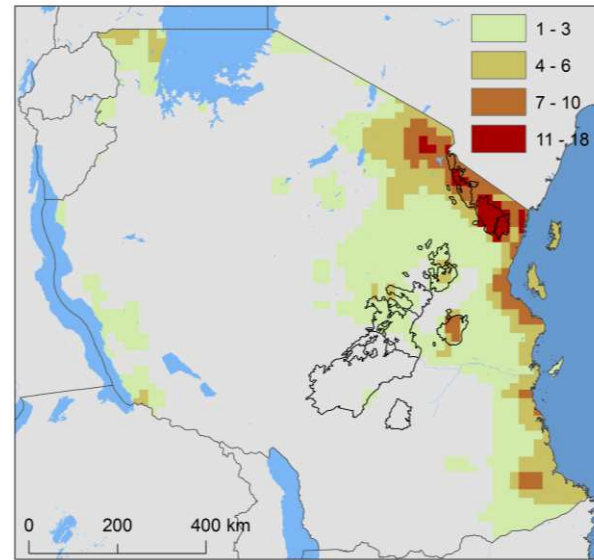


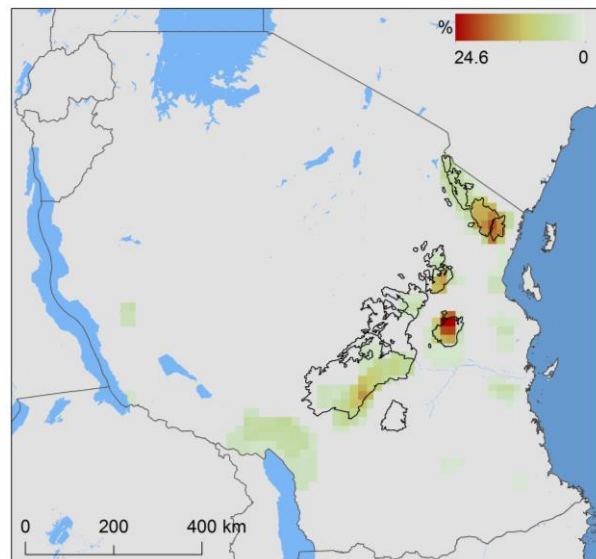
Figure 2. Overall distribution pattern of reptile species richness (a) in Tanzania, in comparison with the richness patterns of amphibians (b), birds (c) and mammals (d). Normalising richness in each group to the interval [0, 1], Taylor diagram (e) shows standard deviations (sd, y-axis) compared with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



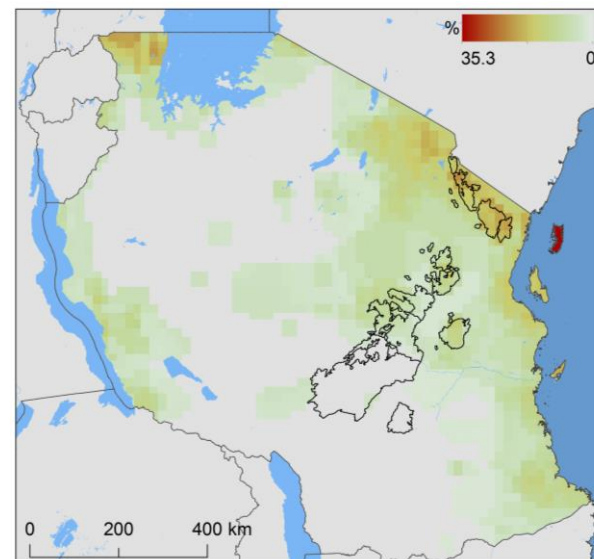
(a)



(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.

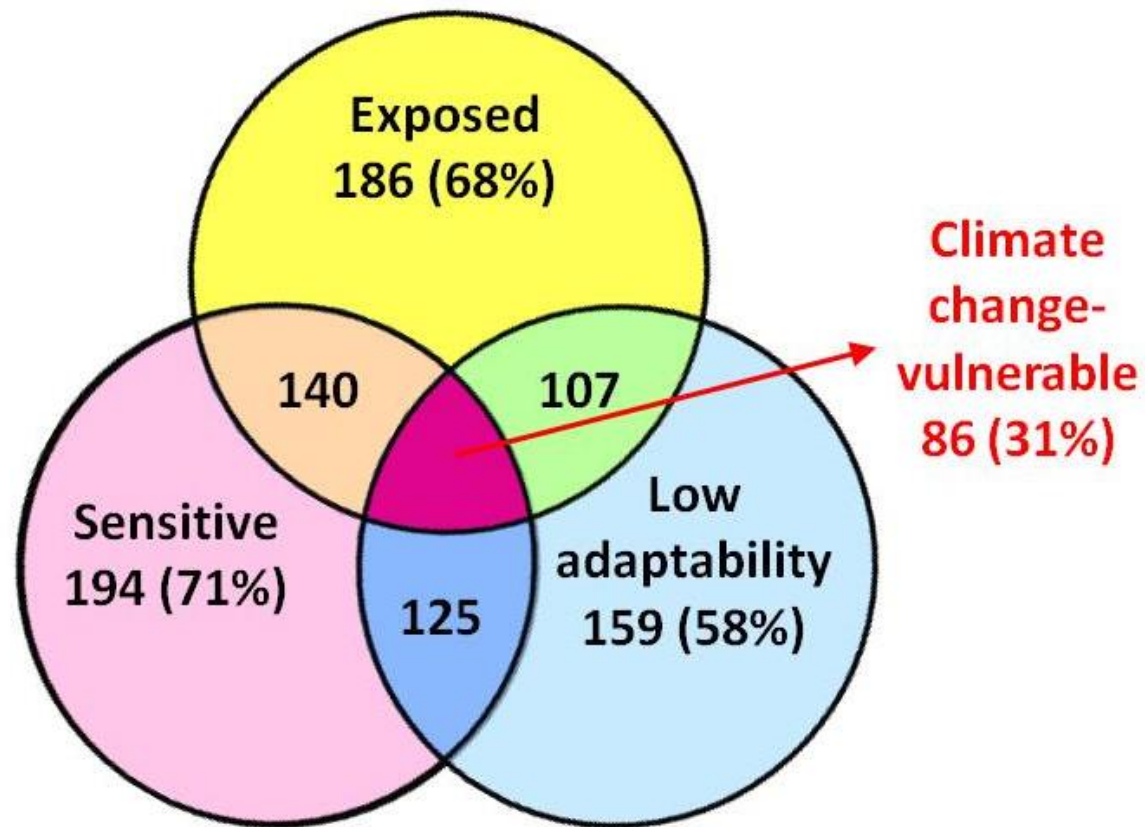


Figure 4. Numbers and percentages of the 274 species considered for the climate change vulnerability assessments falling into each of the three framework dimensions. Measures of exposure use climate projections to 2041-2070 under RCP4.5, and all dimensions treat unknown data points optimistically (i.e.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

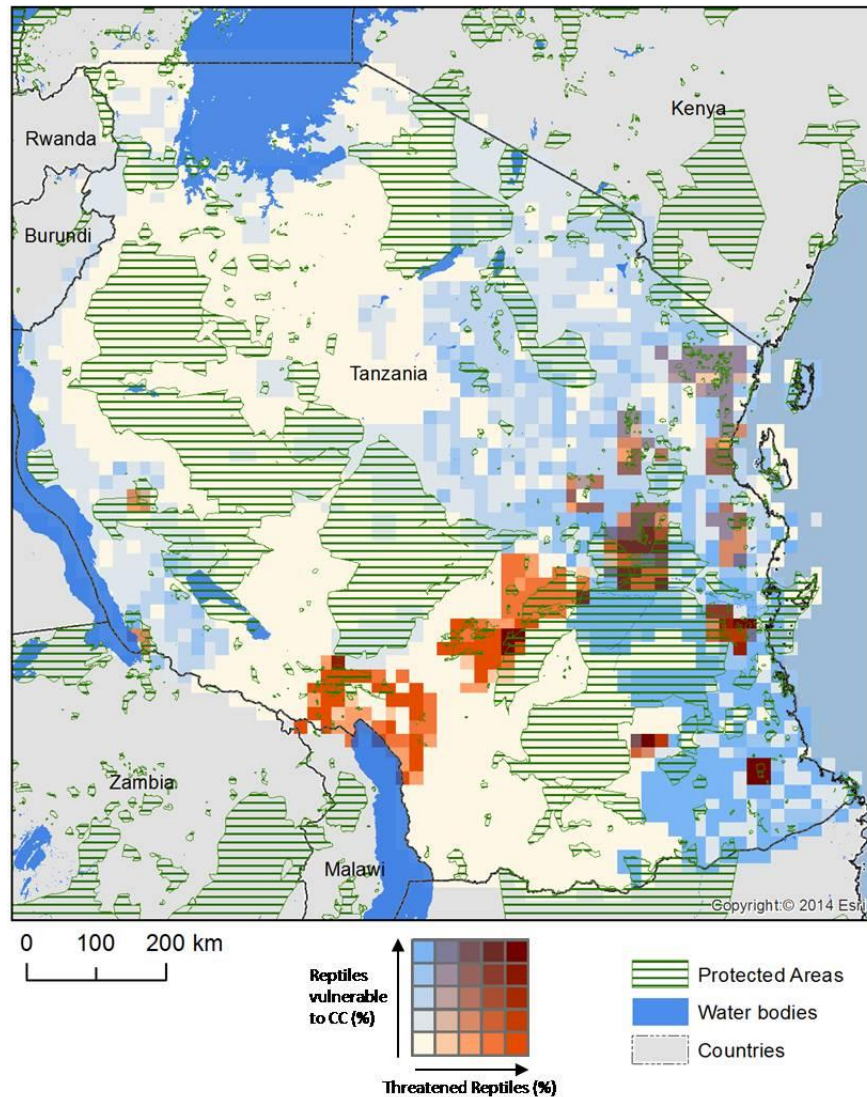


Figure 5. Current protected area network (WDPA; IUCN and UNEP-WCMC, 2014) in Tanzania overlaid on a bivariate map of climate change-vulnerable and globally threatened reptile species. Key gaps in protection of such species are: areas around the north of Lake Malawi, large areas of the Eastern Arc Mountains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