

Extinct, obscure or imaginary: The lizard species with the smallest ranges

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9 **Extinct, obscure or imaginary: the lizard species with the smallest ranges**

10 Running title: lizards known only from type localities

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82 **Abstract**

83 Aim: Small geographic ranges make species especially prone to extinction from
84 anthropogenic disturbances or natural stochastic events. We assemble and analyse a
85 comprehensive dataset of all the world's lizard species, and identify the species with
86 the smallest ranges - those known only from their type localities. We compare them to
87 wide-ranging species to infer whether specific geographic regions or biological traits
88 predispose species to have small ranges.

89 Location: Global

90 Methods: We extensively surveyed museum collections, the primary literature and our
91 own field records to identify all the species of lizards with a maximum linear
92 geographic extent of <10 km. We compared their biogeography, key biological traits
93 and threat status to those of all other lizards.

94 Results: One in seven lizards (927 of the 6568 currently recognized species) are
95 known only from their type localities. These include 213 species known only from a
96 single specimen. Compared to more wide ranging taxa they mostly inhabit relatively
97 inaccessible regions at lower, mostly tropical, latitudes. Surprisingly, we found that
98 burrowing lifestyle is a relatively unimportant driver of small range size. Geckos are
99 especially prone to having tiny ranges, and skinks dominate lists of such species not
100 seen for over 50 years, as well as of species known only from their holotype. Two-
101 thirds of these species have no IUCN assessments, and at least 20 are extinct.

102 Main conclusions

103 Fourteen percent of lizard diversity is restricted to a single location, often in
104 inaccessible regions. These species are elusive, usually poorly known, and little
105 studied. Many face severe extinction risk, but current knowledge is inadequate to
106 properly assess this for all of them. We recommend that such species become the
107 focus of taxonomic, ecological, and survey efforts.

108

109 **Key-words**

110 Accessibility, endemism, extinction, geckos, holotype, range size, skinks, threat, type
111 locality.

112 **Introduction**

113 A prominent feature of the distribution of biodiversity is the extreme variation in
114 species range sizes. Within the same lineage, some species have continental-wide
115 distributions whereas others are restricted to a single locality (Gaston, 2003).

116 Although ranges can be very labile (e.g., Lyons, 2003; Chen et al., 2011, Meiri, Lister
117 et al., 2013; Currie and Venne, 2017), range size is thought to be the product of
118 ecologically relevant traits such as body size, population density and dispersal ability
119 (Brown, 1984; Pimm & Jenkins, 2010; but see Novosolov et al., 2017). Crucially,

120 from a conservation perspective, range size is known to influence extinction risk.
121 Species with small ranges have, everything else being equal, fewer individuals and
122 lower genetic variation than wide-ranging relatives, often leading to elevated
123 extinction probabilities (MacArthur and Wilson, 1967; Caughley, 1994). Threats such
124 as new (or introduced) predators, pathogens and competitors, severe climatic events
125 (e.g., droughts), cataclysms (e.g., fires and volcanic eruptions), and population-level
126 phenomena (e.g., inbreeding depression) can rapidly wipe out narrow ranging species
127 (Purvis et al., 2000). Habitat loss and collection for the pet trade can likewise easily
128 cause species with tiny ranges to go extinct. The elevated threat these species face
129 makes them a particularly relevant for conservation efforts.

130 The importance of range size is reflected in the way extinction risk is evaluated
131 by the International Union for Conservation of Nature (IUCN) Redlist assessments.
132 One of the five criteria the IUCN (2017) uses to evaluate threat, criterion B, uses
133 estimates of range size (defined as the extent of occurrence) to designate extinction
134 probabilities. Although range size per se is insufficient to designate threat, species
135 with ranges smaller than 20,000 km² can qualify as vulnerable under criterion B. To
136 qualify as endangered under criterion B, range size cannot exceed 5000 km², whereas
137 to qualify for the highest level of threat - critically endangered, the threshold is
138 lowered to 100 km² (IUCN, 2017).

139 Although we are often ignorant regarding the true extent of a species' geographic
140 range (because not observing a species somewhere is not sufficient evidence of its
141 absence), we know that ranges can be even smaller than 100 km². Many Southeast-
142 Asian geckos, for example, seem to be confined to isolated karst outcrops (e.g., Ellis
143 & Pauwels, 2012; Wood et al. 2017), never venturing far into the surrounding forest.
144 At the minimum, species must be known from one locality, and a single individual,
145 the holotype, on which the species description is based.

146 Species known only from small ranges are likely to be either difficult to observe,
147 difficult to distinguish from others, or genuinely rare. They may even already be
148 extinct. Several studies have tried to link range size to biological attributes such as
149 body size (e.g., Agosta & Bernardo, 2013) or to geographic attributes such as latitude
150 (Rapaport's Rule; Ruggiero & Werenkraut, 2007). A common finding, however,
151 associates range size not with particular biological attributes, but with the year a

152 species was described (e.g., Gaston et al., 1995; Costello et al., 2015). Generally,
153 scientists observed, distinguished, and described the widely distributed species early.
154 In fact, range size consistently emerges as the key correlate of description date in all
155 tests we know that examined this link (e.g., Collen et al., 2004; Diniz-Filho et al.,
156 2005; Costello et al., 2015; Colli et al., 2016). Species that were discovered and
157 described (as opposed to being split from other species) relatively recently are poorly
158 known almost by definition, given that not enough time has lapsed for biologists to
159 study their biology, abundance, and true range extent. Thus, many recently discovered
160 species may have larger ranges than are currently known.

161 Species that were described early, and remain poorly known (with few or even
162 just a single observation locality), are more likely to truly occupy small ranges, rather
163 than just poorly known ones. They may even already be extinct. Importantly however,
164 some may not be real species. Recent species descriptions often follow modern
165 integrative taxonomic practices, compare more species and specimens, and examine
166 more characters than previous descriptions. The species that remain known only from
167 single specimens sometimes turn out to be based on aberrant or juvenile specimens, or
168 belong to congeners, or even to distantly related species, especially if they were
169 described long ago. For example, *Oreodeira gracilipes* was described as an Australian
170 species based on a single specimen, but was in fact a juvenile African *Agama*
171 (Moody, 1988). *Scelotes schebeni* was described based on a single specimen from
172 Namibia, but was later found to be a *Melanoseps occidentalis*, probably from
173 Cameroon (Bauer, 2016).

174 Correctly identifying the species with the smallest ranges is important in order to
175 uncover the factors affecting geographical range size. It is also of paramount
176 importance from a conservation perspective, as it can suggest how to correctly
177 allocate limited resources to the most threatened species. Many narrow-ranging
178 species are among those in greatest need of conservation effort. Some may already be
179 extinct without us knowing they are (cryptic extinctions). If some of these species are
180 not valid taxonomic entities, we may be wasting conservation resources. Elucidating
181 the ecological and distributional patterns of species known only from their type
182 localities in order to establish the roles of true rarity, lack of records, and taxonomic
183 ambiguities in generating them is thus crucially important.

184 We identify all the species of lizards (Reptilia: Squamata, excluding snakes) that
185 are known only from their type locality (the *terra typica*), the place where the species
186 was described from (henceforth “TL-species”). We examine whether these species are
187 taxonomically or geographically clustered (especially in poorly surveyed regions) and
188 whether they share attributes that may make them easy to overlook, such as small
189 size, fossorial habits (or their correlate: reduced limbs), or nocturnal activity. We
190 compare relevant traits of these TL-species to those of all other lizard species, to
191 highlight the attributes associated with small ranges.

192 We pay special attention to these TL-species that were described relatively early,
193 using an arbitrary cut-off time of 50 years from the present (i.e., 1967 or earlier vs.
194 1968 or later), and compare these species’ traits to those of TL-species described
195 more recently.

196 **Methods**

197 In order to identify the lizard species known only from their type localities, we
198 reviewed and refined a dataset containing range sizes of all the world’s lizards (Roll et
199 al., 2017). We manually reviewed the ranges of all species with ranges smaller than
200 the median size in the global dataset of Roll et al. (2017) to determine whether they
201 are known only from their type locality. For these we manually searched for
202 additional geographic data in the primary and grey literature (using the Reptile
203 Database [Uetz, 2017] and Google Scholar), meta-datasets such as GBIF
204 (www.gbif.org), Vertnet (www.vertnet.org), and the Atlas of Living Australia
205 (www.ala.org.au), IUCN assessments, field guides, and our own observations. We
206 further systematically searched data on these species in scientific journals that have
207 dedicated sections for publishing reptile range extensions (e.g., *Herpetological*
208 *Review*, *Check List*, *Mesoamerican Herpetology*). In addition to the geographic data
209 we further extracted from these sources the latest year in which individuals of each
210 species were observed alive. We used the latest version (May 2017) of the Reptile
211 Database for taxonomy (Uetz, 2017), and excluded all species known only from
212 fossils or sub-fossils. We identified all species that are known only from their type
213 locality. We arbitrarily defined a type locality as having a maximum latitudinal and
214 longitudinal range of <10 km or <0.1 degrees because this represents an extent of
215 occurrence smaller than 100 km² – fitting the IUCN’s criterion B1 for an extent of

216 occurrence of a critically endangered species (IUCN, 2012. Note that as this criterion
217 cannot be applied alone, such species are not necessarily classified as threatened).
218 Species inhabiting more than one island were excluded even if the islands are small
219 and close to each other, as these species cannot be said to inhabit a single locality.

220 We distinguished between species that are only known from old records and
221 those known from recent records (either having been repeatedly found at their type
222 locality or having been described from specimens observed there recently). We
223 arbitrarily placed the cut-off between old and recent records at 50 years ago (1967).
224 Among the older records we further distinguished species known from multiple
225 specimens and those known only from a single specimen, the holotype. Data and
226 metadata of traits used in our comparisons and analyses of lizard groups can be found
227 in Meiri et al. (2012; 2013); Scharf et al., (2015), Feldman et al., (2016), and Vidan et
228 al. (in press).

229 Statistical Analyses

230 Only 12% of the species we identified as known only from their type locality are
231 represented in the large-scale squamate phylogeny of Pyron & Burbrink (2014),
232 effectively preventing us from running phylogenetically informed tests. Instead we
233 explored the effects of individual traits on our classifications of lizards. We used a
234 machine learning procedure to classify lizard species to groups (TL-species vs. broad
235 ranged species, and single specimen vs. multiple specimens). We explored the relative
236 importance of the different traits when used together in these classification
237 procedures. We used a gentle adaptive stochastic boosting classification model
238 (ADA-Boost; Friedman et al. 2000) as our classification mechanism. ADA-Boost
239 distinguishes between cases by combining the outputs of many weak classifiers in
240 order to achieve, through iterations, a powerful classification with low error rates.
241 This procedure has been successfully applied in a wide variety of fields,
242 outperforming many other classifiers (Hastie et al. 2001).

243 To test our predictions we used the following predictors in the classification
244 procedure: description year, the biogeographical realm in (Wallace 1859, 1876)
245 species reside (using the maps of Olson et al. 2001), its activity period (day or night,
246 with cathemeral species counted in both categories), whether it is terrestrial, fossorial,
247 saxicolous or arboreal, whether or not it has reduced legs, its infra-order, body-mass,

248 if it is an insular endemic, and the latitudinal centroid of its range. Our modelling was
249 conducted using the ‘ada’ package in R (Culp et al. 2016) and incorporated an
250 exponential loss function with 50,000 iterations.

251 We further tested whether species only known from type localities are found in
252 remote, difficult to access, regions. To do this we compared the locations of the type-
253 locality-restricted lizard and amphisbaenians for which we had precise locality
254 information (Appendix 1) to the point localities of all ~4550 lizard and
255 amphisbaenians known to be more wide-ranging (Roll et al., 2017). For each point,
256 we extracted its accessibility as measured by the travel time (in minutes, by land or
257 water) to major cities (Nelson, 2008). We then compared the distributions, means and
258 medians of accessibility between point localities of species known only from their
259 type localities with wide-ranging species (whose localities were obtained from
260 literature, observations and museum data; Roll et al., 2017). Extraction of the
261 accessibility information was done using ArcGIS (ESRI, 2011); statistical analyses
262 were conducted using R.

263

264 **Results**

265 The Dataset

266 We identified 927 species of lizards that are, as far as we know, restricted to their
267 type locality (i.e., an area with a linear extent no larger than 10 km or 0.1 of a degree;
268 Appendix 1). They represent fully 14.1% of all lizard diversity (6569 species, Uetz,
269 2017, supplemented with additional species described until September 1st, 2017). Of
270 these 927 species, 756 were observed in the wild in the last 50 years (since 1968),
271 whereas 171 were last seen between 1830 (*Diploglossus microlepis* [Gray, 1831]) and
272 1967 (e.g., *Calotes bhutanensis*, Biswas, 1975). Only 191 species were seen alive
273 after they were described, whereas the other 736 (79%) were last seen alive when the
274 holotype or type series was collected. Two hundred and thirteen species are only
275 known from their holotype (Appendix 1; 112 species observed during the last 50
276 years, 101 species only observed earlier).

277 The geography of small-ranged lizards

278 Lizards known only from their type localities inhabit mostly tropical regions and
279 some arid regions (although the Sahara and Sahel, for example, have few TL-species).
280 Those known only from old records show a more restricted, almost entirely tropical,
281 distribution (mean absolute value of latitude: $11.3 \pm 9.2^\circ_{SD}$), especially in Indonesia,
282 equatorial Africa, northern and western South America and the Caribbean (Figure 1).
283 More recently observed species have additional hotspots, in both tropical and desert
284 regions (e.g., in Australia, Argentina and Chile, Madagascar, New Caledonia, Iran,
285 north-western Mexico and Southern Asia, mean of absolute value of latitude:
286 $15.7 \pm 9.6^\circ$; Figure 1).

287 Overall, TL-species also tend to inhabit somewhat lower latitudes than large-
288 ranged species (absolute latitude 14.9° vs. 18.5° , $t_{905,5607} = 9.40$, $p < 0.0001$). They are
289 relatively rare in the Nearctic, the Palearctic and Australia (8%, 5% and 5% of the
290 lizard fauna, respectively), but comprise 28% of the lizard species in the Oriental
291 realm.

292 Taxonomic composition

293 Geckos (Gekkota) dominate the list of TL-species (335 of 927 species, 36%),
294 followed by skinks (210, 24%), and anoles (58, 6%; Table 1). The list TL-species not
295 observed in the last 50 years, however, is dominated by skinks (69 of 171 species,
296 40%), followed by geckos (31 species, 18%), and amphisbaenians (14, 8%).
297 Interestingly, this is mirrored in the taxonomic composition of the species known only
298 from their type specimen (regardless of when it was collected), for which skinks are
299 the largest group (72 of 213 species, 34%), followed by geckos (45 species), agamids
300 (16), anoles (15) and both gymnophthalmids and amphisbaenians (14; Table 1). The
301 Dibamidae has the highest proportion of species only known from the type locality
302 (11 of 23 species; 48%), followed by Anniellidae (2 of 6 species; 33%),
303 Hoplocercidae (26%), and three gecko families: Gekkonidae (23%), Carphodactylidae
304 (23%), and Eublepharidae (22%). Twelve of 42 families have no TL-species. All are
305 species poor (the largest is the 12-species Crotaphytidae).

306 Traits of lizards known only from their type localities

307 Lizards known only from their type localities have generally been described later
308 than wide-ranging species (by 58 years on average, $t_{927,5641} = 27.3$, $p < 0.0001$; Figure

309 2). Most (3142 of 4366; 72%) of the wide- ranging species for which we have data are
310 diurnal (22% nocturnal, 6% cathemeral). Those known only from their type localities
311 tend more towards nocturnality (232 of 612 species, 38%, vs. 59% diurnal, and 3%
312 cathemeral; $\chi^2 = 73.9$, $p < 0.0001$; all χ^2 values are for 2*2 tables). This is especially
313 the case for the TL-species observed in the last 50 years (39% nocturnal), as would be
314 expected by the high proportion of geckos among them. We only know the activity-
315 times of 46 TL-species that were last seen before 1968, whereas those of 127 of them
316 (73%) are unknown.

317 Contrary to our expectations, fossorial species were not more dominant among
318 species known only from the type locality, Assuming all amphisbaenians and
319 dibamids are fossorial 12.2% (86 of 701 species with known habits) of the TL-species
320 are fossorial vs. 10.2% (557 of 4913) lizards with wider ranges ($\chi^2 = 0.46$, $p = 0.53$).
321 Species known only from their type localities were more associated with rocky
322 substrates (39% species fully or partially saxicolous, vs. 26% of the wider ranging
323 species; $\chi^2 = 52.5$, $p < 0.0001$). The maximum body mass of wider-ranging species is
324 71% higher, on average, than those known only from their type localities (back-
325 transformed from logarithms: average 10.2 ± 5.0 g vs. 6.0 ± 4.2 g, $t_{910,5634} = 9.38$, $p <$
326 0.0001 ; Figure 3; non- transformed averages are 135 & 32g, respectively). This
327 difference is retained when we compare sizes within families (as recognized by Uetz,
328 2017; average difference 41%, $t = 7.84$, $p < 0.0001$).

329 Classifications analysis

330 We used our classification procedure to distinguish between TL-species and
331 species with wider ranges for which we had data for all the traits we coded (4237
332 wider ranging species, 555 TL-species). Our model managed to classify the two
333 groups nearly perfectly, with a cross validated training error of 0% and an out-of-bag
334 error rate of 1.7%. These traits can thus be used to successfully distinguish TL-species
335 from wider-ranging species. Figure 4 depicts the relative importance of the different
336 traits in the classification procedure, and the associated partial dependence plots are
337 shown in Appendix 2. They highlight the importance of low latitude and infraorder
338 affiliation in the classification, as well as the roles of biogeographic realm, low body
339 mass and late description year.

340 In our classification of TL-species known either from one (62 species) or multiple
341 specimens (493 species) the model achieved perfect classification between the groups
342 with a cross validated error of 0% (both training and out-of-bag). For this
343 classification most attributes played an important role. Realm and infraorder
344 affiliation, fossoriality and the degree of leg reduction (species known only from their
345 holotype tend to be fossorial, limbless, or with reduced legs; see Appendix 3 for
346 variable importance), were the best classifiers.

347 Accessibility and threat

348 The accessibility (time to major cities, in minutes) of the localities of the 868 TL-
349 species in our database, for which such data could be calculated, ranged from 8
350 minutes for the aptly named *Cyrtodactylus metropolis* (Grismer et al., 2014) to 7432
351 minutes (= 5.16 days) for the Venezuelan *Adercosaurus vixadnexus* (Myers &
352 Donnelly 2001). These 868 points are generally found in inaccessible places
353 compared to the 136,840 unique localities for which we have data for wide-ranging
354 lizard species (Figure 5). The mean (518 minutes = 8.6 hours) and median (319
355 minutes = 5.3 hours) inaccessibility values are greater for species known only from
356 their type localities than those of wide-ranging species (by 34% and 49%,
357 respectively; $t = -5.16$, $df = 873.8$, $p < 0.0001$).

358 Of the 927 species known only from their type locality 625 (67%) have no IUCN
359 assessment (as of September 2017). Of the 302 assessed species, six are Extinct, 126
360 (42%) are Data Deficient (DD), and 93 (31%) are listed as threatened: 35 Vulnerable
361 (VU), 16 Endangered (EN), and 42 Critically Endangered (CR). Seventy-seven
362 species are classified as non-threatened (25%): 61 Least Concern (LC) and 16 Near
363 Threatened (NT; IUCN 2017). The respective proportions for wide-ranging lizards are
364 11% DD, 19% threatened and 69% non-threatened species. The populations of 26
365 species are assessed as decreasing, and of 58 (including *Lipinia zamboangensis*, last
366 seen in 1959, and the extinct *Tachygyia microlepis*) as stable. For most species, the
367 population status is unknown (202 species) or has not been assessed (625 species).
368 None are increasing.

369 Of the 171 species seen only before 1968, sixty-five have been assessed. Fifty
370 one are listed as Data Deficient. One African skink, *Panaspis helleri* (Loveridge
371 1932), is classified as Least Concern although as far as we are aware it is only known

372 from its holotype (although a specimen in the Royal Museum for Central Africa
373 [RMCA] from 2.70°S, 27.33°E, ~450 km from the type locality of *P. helleri* in
374 Bugongo Ridge, Mt. Ruwenzori, DRC, may prove to also belong to this species, DM,
375 pers. obs.). Seven are listed as threatened (2 VU, 1 EN and 4 CR). Finally, the IUCN
376 lists six species in our list as extinct (*Celestus occiduus*, *Hoplodactylus delcourti*,
377 *Leiocephalus herminieri*, *Leiocephalus eremitus*, *Tachygyia microlepis*, and
378 *Tetradactylus eastwoodae*). Slavenko et al. (2016), however, lists 20 species known
379 only from their type localities (2.2%) as extinct (as well as 20 extinct wide-ranging
380 species; 0.4%).

381 Discussion

382 We found that 927 of the world's lizard species — nearly one in seven of the
383 currently recognized 6568 species — are known only from the lowest end of the range
384 size spectrum, basically from their type locality alone. Furthermore, 736 of them have
385 never been recorded after being described, which was more than 50 years ago for 162
386 of them. No fewer than 213 species are only known from a single specimen.

387 Many species may indeed have extremely small ranges, particularly the 64
388 species residing on islands with <10 km maximum linear extent (e.g., *Anolis*
389 *ernestwilliamsi*, Lazell, 1983), as well as cave and rock associated endemics (e.g.,
390 *Cyrtodactylus hontreensis*, Ngo et al., 2008). Others may be more wide ranging but
391 were either only recently described or elevated to species level, have cryptic lifestyles,
392 or inhabit poorly surveyed or difficult-to-access regions. Our results highlight those
393 species of lizards (and those regions, e.g., Indonesia) that are in most desperate need
394 of further work to assess their true ranges.

395 Our definition of a type locality, as an area with a maximum known linear extent
396 of less than 10 km, is arbitrary. The range sizes of lizards in general, however, are
397 distinctly bimodal, with a pronounced mode of tiny ranges (<30 km²), followed by a
398 relatively symmetrical distribution around 100,000 km² (Roll et al., 2017). Thus,
399 although a type locality vs. wider-ranging dichotomy of some sort seems justified,
400 there is nothing special about our chosen cut-off. A similar argument can be made
401 regarding our decision to place the early vs. late cut-off at 50 years ago. We arbitrarily
402 chose this value to represent a time span that is about the same as a long career in
403 herpetology and much longer than the lifespan of nearly all lizards (Scharf et al.,

2015). It also approximately marks an era of expanded research into lizard systematics, with 44% of all lizard species described since 1967 (the median year is 1947). The 1950s and 1960s were a time of few lizard species descriptions (Figure 2, see also Pincheira-Donoso et al., 2013), and the 1960s and 70s are often thought to be when global warming started to strongly affect the phenology and ranges of organisms (e.g., Walther et al., 2002). Thus, contrasts based on these arbitrary numbers serve to illustrate important points: many lizards are known from single localities, and many of them have not been seen for a very long time, during which many important changes (e.g., habitat loss, climate change) have occurred.

413 Taxonomic considerations

414 Some of the species in our dataset may not be real species but belong to other, 415 better known and more widely ranging species (Isaac et al., 2004; Meiri & Mace, 416 2007). Many of the ‘older’ species we list here are known from very few specimens, 417 and some have been lost. For example, the holotype (and only specimen) of *Chalcides* 418 *pentadactylus* (Beddome, 1870) was lost before 1935 (Smith, 1935), and the holotype 419 of *Lipinia miangensis* (Werner, 1910) was destroyed during World War II. Others are 420 in a poor state of preservation (e.g., *Liolaemus melanopleurus*, Pincheira-Donoso & 421 Nuñez, 2005, *Capitellum parvicruzae*, Hedges & Conn, 2012). This makes it difficult 422 to assess whether they are indeed distinct from other, better known, and more widely 423 ranging species. Even some recently described species are known from very old 424 specimens that long remained unidentified in scientific collections. For example, 425 *Mabuya guadeloupe* (Hedges & Conn, 2012) and *Hemidactylus endophis* (Carranza 426 & Arnold, 2012) are based on specimens dating back to 1892 and 1887, respectively 427 (Hedges & Conn, 2012; and Salvador Carranza, pers. comm. to SM). This also likely 428 means that they were kept in preservatives that left little DNA accessible for genetic 429 analysis. That said, some of the species we identify as being known only from their 430 type locality — especially those known just from the holotype — have long been 431 known as requiring further taxonomic evaluation (e.g., *Leiolopisma fasciolare*, *Salea* 432 *gularis*, and *Trachylepis betsileana*; Zug, 1985; Smith, 1935; Nussbaum et al., 1999; 433 respectively). Together with more survey work, taxonomic revision of some of these 434 lizards is strongly warranted.

435 Traits of lizards known only from their type localities

436 In general, TL-species have a unique set of attributes that distinguishes them
437 from wider ranging species. We identify some traits that may make these species
438 difficult to find, such as relatively small size and nocturnal behaviour. It is important
439 to interpret these findings cautiously given that, for example, the apparently small
440 body size of most TL-species we list may be an artefact of the use of maxima to
441 represent lizard sizes (Meiri, 2008). Coupled with small sample size this will
442 automatically result in small inferred body sizes (Meiri, 2007). That said, the large
443 effect-size we identify (see above) makes it unlikely that all the size differences could
444 be ascribed to sampling. Nocturnality may make lizards more difficult to detect,
445 possibly meaning that the recent increased rate of finding nocturnal TL-species could
446 reflect the increased use of head-torches (which also resulted in finding new species
447 of diurnal lizards, e.g., anoles and chameleons, which were detected sleeping on
448 branches, e.g., Poe et al., 2015). It may also reflect the propensity of geckos to have
449 narrow ranges, tropical distribution, and nocturnal behaviour (Gamble et al., 2015;
450 Meiri, 2016; Vidan et al. 2017). Indeed, the propensity of geckos to specialize in
451 using specific and naturally isolated substrates (usually rocks; e.g., Giri et al., 2009;
452 Grismer, 2010, Pauwels & Sumontha, 2014; Oliver & Doughty, 2016; Oliver et al.,
453 2016; Heinicke et al., 2017; Wood et al., 2017) and speciate where these are found,
454 may predispose them to often have very small ranges. Large, relatively continuous
455 patches of habitat, such as Amazonia and the Sahara, on the other hand, harbour many
456 lizard species (Roll et al., 2017), but harbour fewer TL-species (Figure 1).

457 Surprisingly, we did not find that burrowing lifestyle makes lizards more likely to
458 have tiny ranges. Living underground may not only make species difficult to find, but
459 may also seriously limit their dispersal abilities. The obligatory fossorial
460 amphisbaenians, however, have a similar proportion of species known only from the
461 type locality to that of non-fossorial lizards (31 species, 2.2% vs. 166, 3.3% of the
462 more wide-ranging species). The mostly fossorial and secretive dibamids, however,
463 have the highest ratio of TL-species of all lizard families. The high percentage of
464 recently described geckos could have 'diluted' the signal of fossorial taxa. On the
465 other hand, habitats used by fossorial reptiles are often extensive, whereas some
466 exposed rock escarpments that specialized saxicolous lizards (e.g., many geckos) use
467 are small and relatively stable over evolutionary time, mediating persistence. It should
468 be noted, however, that many species known only from their type localities, especially

469 some of the skinks, are so poorly studied that we have no data indicating whether they
470 are fossorial or not.

471 Threat status

472 By definition, species known from only a few specimens are also relatively little
473 known. This is especially true for species known only from old records and from few
474 or even single specimens. Thus, even though the IUCN guidelines explicitly say that
475 “the liberal use of ‘Data Deficient’ is discouraged”; (IUCN, 2012), DD is the most
476 commonly ascribed status for the species we analysed here, and rightfully so. We
477 suggest that DD species are probably rare (or they would be easier to ascribe to
478 another category; cf. Bland & Bohm, 2016). We think that, until more data are
479 gathered, species known only from a single specimen cannot be ascribed any status
480 other than DD – or extinct. They may reasonably be listed as threatened if their
481 habitat is known to be deteriorating, but then perhaps they are already extinct. If their
482 habitat is large and relatively intact they may well be doing fine, but current
483 knowledge probably precludes us from making any strong inference. Forty-six species
484 in our list (Appendix 1) are assessed as non-threatened despite being known only
485 from their original description. Four of them (*Panaspis helleri*, *Liolaemus lopezi*,
486 *Adercosaurus vixadnexus*, and *Loxopholis hoogmoedi*) are assessed as Least Concern
487 while being known from just one individual (but see above for *P. helleri*). We suggest
488 they may not be sufficiently well known to merit such a positive assessment.

489 Species known only from a single locality, especially if they have not been seen
490 for a long time, may already be extinct. Only six species in our list are formally
491 recognized as extinct by the IUCN. Redlisting is not yet complete for reptiles (only
492 51%, 5338 of > 10500 species as of May 2017), and several species most likely
493 extinct (e. g., *Phelsuma edwardnewtoni*) are not yet listed by the IUCN. Twenty
494 species we identify here (Appendix 1) as being known only from their type localities
495 were listed as extinct by Slavenko et al. (2016). These include forms that have not
496 been seen for decades, despite repeated surveys (e.g., *Alinea lanceolata*, Hedges &
497 Conn, 2012), and species that were recently described based on old specimens (e.g.,
498 *Tarentola albertschwartzi*, Sprackland & Swinney, 1998, and many of the skinks
499 described by Hedges & Conn [2012], such as *Mabuya guadeloupae* and *Capitellum*
500 *parvicruzae*). In contrast, Slavenko et al. (2016) identify exactly the same number

501 (20) of extinctions in species we consider more wide-ranging. Thus species known
502 only from the type locality are 7-times more likely to have gone extinct than wider
503 ranging ones. Even these numbers may underestimate the actual extinction rates of
504 species known only from the type locality – as many of them were not seen for
505 decades. We suggest that species not seen for 50 years or more are reviewed as a
506 matter of priority by the IUCN, and are surveyed for in their last (and only) known
507 locality by conservation agencies and herpetologists alike.

508 Conclusions

509 Range-restricted species, true narrow endemics, are critical for the study of
510 evolution, bioregionalization processes, small-population ecology and conservation
511 (Whittaker et al., 2005; Nogueira et al., 2011). In general, lizards (and amphibians)
512 have much smaller ranges than other vertebrates (e.g., Anderson, 1984; Lewin et al.,
513 2016, Roll et al. 2017). They may thus be particularly important proxies for patterns
514 of endemism in other, poorly known narrow-ranging taxa (e.g., most invertebrate
515 taxa). Our work demonstrates that we still poorly understand the status of even the
516 narrow-ranging taxa already described - many may well be threatened, or even
517 extinct, but at the moment we simply lack adequate data to assess their status. At the
518 same time, the rate of accumulation of newly described endemics is increasing
519 (Figure 2), suggesting that endemism levels in many regions and habitats remain
520 underestimated. Thus, above all else, this work underlines the critical importance of
521 careful, targeted surveys in nature and of integrated taxonomic analyses, to refine our
522 understanding of which narrow-ranging lizards are valid species, which are likely to
523 be already extinct, and which are in dire need of protection.

524

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734 Data Accessibility Statement: All data and references on the species known only from
 735 their type localities are included in Appendix 1.

736 Biosketch: The research team is dedicated to the study of lizard taxonomy, biology,
 737 and biogeography, as well as to lizard conservation. Author Contributions: SM
 738 conceived and designed the study, UR and SM analysed the data, all the authors
 739 helped collect and verify the data, SM wrote the paper. All the authors helped the
 740 writing.

741 Supplementary Material may be found in the online version of this article:

742 Appendix 1: data and metadata on the species known only from their types.

743 Appendix 2: partial dependence plots for the classifications analysis

744 Appendix 3: variable importance figure for the classifications analysis

745

746

747 **Table 1**: Lizards known only from their type localities vs. wider ranging species
 748 within families

Family	TL-species	holotype only	wider- ranging species	Proportion of TL- species
Gekkonidae*	261	33	867	23%
Scincidae	210	72	1414	13%

Dactyloidae	58	15	361	14%
Liolaemidae	52	6	255	17%
Agamidae	48	16	439	10%
Gymnophthalmidae	42	13	220	16%
Amphisbaenidae	31	13	147	17%
Sphaerodactylidae*	31	7	184	14%
Chamaeleonidae	28	3	178	14%
Anguidae	23	11	106	18%
Tropiduridae	20	3	116	15%
Lacertidae	15	6	311	5%
Phyllodactylidae*	15	2	122	11%
Diplodactylidae*	12	3	137	8%
Dibamidae	11	5	12	48%
Eublepharidae*	8	0	28	22%
Carphodactylidae*	7	0	23	23%
Phrynosomatidae	7	0	147	5%
Teiidae	7	0	149	4%
Leiocephalidae	6	1	25	19%
Varanidae	6	2	73	8%
Xantusiidae	6	0	28	18%
Cordylidae	5	0	63	7%
Hoplocercidae	5	0	14	26%
Iguanidae	5	0	38	12%
Gerrhosauridae	3	2	34	8%
Anniellidae	2	0	4	33%
Leiosauridae	1	0	32	3%
Pygopodidae*	1	0	45	2%
Xenosauridae	1	0	10	9%
Bipedidae	0	0	4	0%
Blanidae	0	0	6	0%
Cadeidae	0	0	2	0%
Corytophanidae	0	0	9	0%
Crotaphytidae	0	0	12	0%

Helodermatidae	0	0	2	0%
Lanthanotidae	0	0	1	0%
Opluridae	0	0	8	0%
Polychrotidae	0	0	7	0%
Rhineuridae	0	0	1	0%
Shinisauridae	0	0	1	0%
Trogonophiidae	0	0	6	0%

749

750 Lizard species in each family that are known from their type locality only (“TL-
 751 species”, maximum linear extent of <10 km; 1st column), and only known from the
 752 holotype (2nd column), vs. the number of more widely ranging species (3rd column;
 753 maximum linear extent >10 km). The fourth column is the proportion of species
 754 known from their type locality out of all species in the family. Gecko families are
 755 marked with an asterisk.

756

757 **Figure Legends**

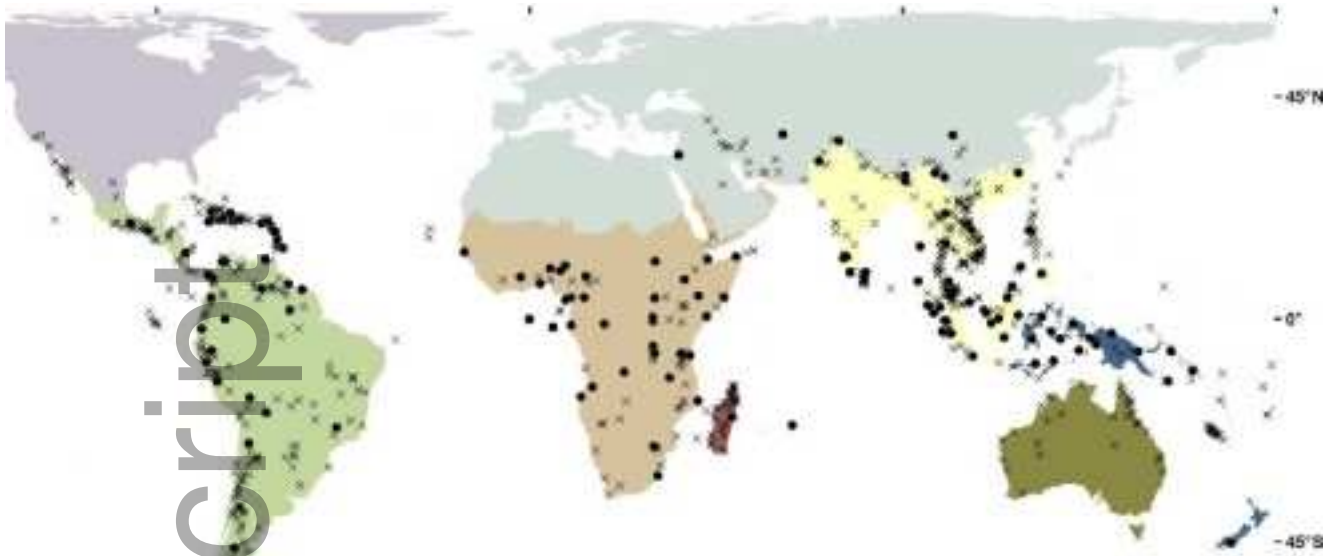
758 **Figure 1.** Lizard species known only from their type localities. Circles: species not
 759 observed after 1967 (n = 151). Crosses: species observed after 1967 (n = 754).
 760 Eighteen species could not be mapped. Underlying colours represent the
 761 biogeographic realms. Equal-area Behrmann projection.

762 **Figure 2.** Decades when wide-ranging lizards (dark grey; 5641 species) and species
 763 known only from their type localities (light grey; 927 species) were described.
 764 Frequency is the proportion of species in each category (TL-species and wider
 765 ranging species) described in a given decade.

766 **Figure 3.** Maximum body masses of wide-ranging lizard species (dark grey, 5634
 767 species) and species known only from their type localities (light grey, 910 species).
 768 Frequency is the proportion of species in each category (TL-species and wider
 769 ranging species) in a given mass bin. Masses (in grams) are log-10 transformed.

770 **Figure 4.** The relative importance of different traits in classifying lizards to the TL-
771 species vs. wider ranging species groups (555 and 4237 species in each group,
772 respectively, for which data on all traits are known)

773 **Figure 5.** Accessibility of lizard species known only from type localities (pink, red
774 lines) vs. wide-ranging species (blue). The plots depict histograms of accessibility (=
775 travel time to major cities, in minutes) of localities from which TL-species and wider
776 ranging lizards are known (dashed lines: mean values, full lines: median values - full
777 lines).



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Proportion

