Biological Conservation 278 (2023) 109879

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Perspective

Done but not dusted: Reflections on the first global reptile assessment and priorities for the second

Shai Meiri[a,b,*], David G. Chapple[c], Krystal A. Tolley[d,e], Nicki Mitchell[f], Timrat Laniado[a], Neil Cox[g], Phil Bowls[g], Bruce E. Young[h], Gabriel Caetano[i], Julia Geschke[j,k], Monika Böhm[j,k], Uri Roll[i]

[a] School of Zoology, Faculty of Life Sciences, Tel Aviv University, Tel Aviv 6997801, Israel
[b] The Steinhardt Museum of Natural History, Tel Aviv University, Tel Aviv 6997801, Israel
[c] School of Biological Sciences, Monash University, Victoria 3800, Australia
[d] South African National Biodiversity Institute, Kirstenbosch Research Centre, Private Bag X7 Claremont, Cape Town, South Africa
[e] Centre for Ecological Genomics and Wildlife Conservation, University of Johannesburg, Auckland Park, 2006 Johannesburg, South Africa
[f] School of Biological Sciences, The University of Western Australia, Western Australia 6009, Australia
[g] Biodiversity Assessment Unit IUCN-Conservation International, Washington, DC, USA
[h] NatureServe, Arlington, VA, USA
[i] Mitrani Department of Desert Ecology, The Swiss Institute for Dryland Environments and Energy Research, The Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Midreshet Ben-Gurion 849900, Israel
[j] Global Center for Species Survival, Indianapolis Zoo, Indianapolis, IN 46222, USA
[k] IUCN Species Survival Commission, Gland, Switzerland

ARTICLE INFO

Keywords:
Data deficiency
IUCN Red List assessments
Red List Index
Reptilia
Squamates

ABSTRACT

The IUCN recently coordinated the first assessment of extinction risk of the world's reptile species. This monumental undertaking allows, for the first time, an examination of threats and prioritization of conservation effort, not just for reptiles, but for land vertebrates as a whole. Reptiles are now the largest class of land vertebrates in terms of species numbers. The dynamic nature of reptile taxonomy, the 18 years it took for the Global Reptile Assessment to be completed, the poor state of knowledge for many species – especially of squamates – and the evolving nature of threats, however, all highlight the need for continued monitoring of reptile species and threats. Here we review the status of reptile conservation assessments, and identify the challenges facing the next reptile assessments. We then recommend potential avenues that could facilitate efficient, accurate and timely future assessments.

After 18 years of toil, the first global reptile assessment (GRA) by the International Union for the Conservation of Nature (IUCN) Red List was concluded (Cox et al., 2022). The GRA represented the combined efforts of over 900 reptile experts from all over the world. The GRA greatly improved the only previous assessment of the conservation status of the world's reptiles, which had focused on a randomly sampled subset of 1500 species (Bohm et al., 2013). The 10,196 reptile species now assessed for the GRA (Cox et al., 2022) is nearly double the number of species assessed during the first comprehensive global assessments of other land vertebrate classes (amphibians: 5743 species, Stuart et al., 2004; mammals: 5487 species, Schipper et al., 2008; 1029 threatened birds in 1988, Collar and Andrew, 1988) and substantially increases our knowledge of reptile conservation status and needs worldwide.

Although the first GRA represents an important first step in providing updated assessments for all reptiles, the rapid rate of species descriptions, and elevations from synonymy, has left 1970 reptile species unassessed (16.5 % of the ~11,930 reptile species recognized in December 2022; Uetz, 2022; the lists are not 100% overlapping). In general, attention to, and knowledge of, reptile conservation has lagged behind that of other terrestrial vertebrate groups (Tingley et al., 2016). For example, the first GRA was completed 14–34 years after equivalent comprehensive assessment of other terrestrial vertebrate groups (Stuart et al., 2004; Schipper et al., 2008; note that assessments for all taxa have become increasingly detailed over time). In the intervening time, the second Global Amphibian Assessment is nearing completion (IUCN SSC Amphibian Specialist Group, 2022), birds have been re-assessed

* Corresponding author at: School of Zoology, Faculty of Life Sciences, Tel Aviv University, Tel Aviv 6997801, Israel.
E-mail address: uncshai@tauex.tau.ac.il (S. Meiri).

https://doi.org/10.1016/j.biocon.2022.109879
Received 21 July 2022; Received in revised form 14 December 2022; Accepted 20 December 2022

multiple times (Collar et al., 1994; BirdLife International, 2000, 2004, Butchart et al., 2004 and now in annual batches) and some mammals are regularly re-assessed (Global Mammal Assessment, 2022).

Comprehensive assessments provide valuable data regarding the plight of taxa which, in turn, inform global policy and reporting. For example, the United Nations used the Red List Index (RLI, calculated from changes in species' Red List status) as the primary indicator to demonstrate the deteriorating state of biodiversity (Brondizio et al., 2019). Similarly, the data underlying these large-scale Red List efforts underpin both species- and area-based conservation prioritizations (e.g., Key Biodiversity Areas; Alliance for Zero Extinction), and threat abatement efforts such as those advocated through the STAR metric (Species Threat Abatement and Restoration; Mair et al., 2021). Red List assessments are also linked to additional assessment processes focused on conservation impact, such as the Green Status of Species (Grace et al., 2021). Crucially, almost all countries are parties to the Convention on Biological Diversity (CBD) and are therefore required by this international treaty to regularly report on the status of their biodiversity, with globally disaggregated RLIs, or RLIs derived from national assessments, serving this purpose.

While the Red List Index has been estimated for some vertebrate groups multiple times, both globally and nationally (e.g., Hayward, 2011; Juslen et al., 2013; Renjifo et al., 2020), a Red List Index for reptiles globally cannot yet be computed. With the first global assessment of reptiles now at hand, it is timely to reflect on the monumental achievement of the first GRA (Cox et al., 2022), and to identify priorities for the immediate future of the GRA with an aim toward better representation of reptiles in the IUCN Red List Index. We offer the following suggestions in this spirit.

1. Increase the proportion of reptile species assessed

The first GRA completed assessments for 85 % of currently recognized reptile species (10,196 of ~11,950 species, Uetz, 2022 and newer descriptions), with 10,148 currently appearing on the IUCN Red List website (IUCN, 2022). For comparison, as of December 2022, 88 % (7486 of 8536) of amphibian species (https://amphibiansoftheworld.amnh.org/; note that the second global amphibian assessment is due to be published in 2023), 90 % (5968 of 6596) of mammal species (ASM Mammal Diversity Database, version 1.9; https://www.mammaldiversity.org/), and all 11,162 species of birds (https://www.birdlife.org) have Red List assessments (Fig. 1). For reptiles, while Rhodin et al. (2021) propose assessment categories for all 357 turtle species, only 270 species appear on the Red List website (https://www.iucnredlist.org/search). The majority of Crocodylia (23 of 27 species; 85 %) and Squamata (9680 of ~11,540 species, 84 %) have been assessed, as has the single representative of the Sphenodontidae (the tuatara). Thus the conservation needs of reptiles, especially the most specious group – the squamates – are not as well-known as those of other tetrapod taxa. Many newly described squamates that were not included in the first GRA have small known ranges and populations (Meiri, 2016). Consequently, if threats are operating, these newly described species will likely warrant a threatened Red List category (Vulnerable: VU, Endangered: EN, or Critically Endangered: CR), at a higher proportion than for assessed species (Caetano et al., 2022; see also points 4 & 6, below).

The sheer number of squamate species, and the highly dynamic nature of their taxonomy (see Priority 4) – especially the great increase in describing new species, elevating subspecies and recognizing synonyms as distinct, pose significant challenges for achieving a complete assessment of the group (e.g., Chapple et al., 2021). Overcoming this will require dedicated resources, targeted research (see Priority 5), global coordination, and extensive contributions from reptile conservation biologists (see Priority 7).

Fig. 1. The proportions of amphibian, bird, mammal and reptile species with up to date (green) or outdated (yellow) IUCN Red List classifications, Data Deficient classifications (grey) and Not Evaluated species (pink). Figurine heights are proportional to the number of species in each class. Data for Red List classifications are from the IUCN (2022); Numbers of Not Evaluated species are based on numbers of amphibians from https://amphibiansoftheworld.amnh.org/ (downloaded on 27th of April 2022), birds from http://datazone.birdlife.org/species/taxonomy (HBW-BirdLife_List_of_Birds_v6 Dec2021), mammals from https://www.mammaldiversity.org/ (version 1.9, April 2022) and reptiles from the 08-03-2022 version of the Reptile database (Uetz, 2022). The numbers of unassessed species may be slightly higher (i.e. underestimated in the figure) than depicted where the IUCN Red List recognizes species that are not recognized in these datasets. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Address knowledge gaps for Data Deficient species

Lack of knowledge regarding species conservation status and needs is also manifested in species assigned to the Data Deficient (DD) category (Bland and Böhm, 2016). Fifty species of birds (0.4 %), 840 mammal species (22 %), and 1193 amphibian species (28 %; IUCN, 2022) are currently classified by the IUCN as Data Deficient. In comparison, 1489 reptile species (26 %) are Data Deficient (Cox et al., 2022) (Fig. 1; this may in part be because birds have larger ranges). We suspect that many Data Deficient species would be assessed as threatened in the future because they often have similar attributes (e.g., small ranges, high levels of human pressure across their ranges) to species assessed as threatened (Gumbs et al., 2020). This assertion is supported by recent studies using an automated extinction risk assessment process through machine learning that has predicted that Data Deficient reptile species are substantially more likely to fall within a threat category than expected given the overall percentage of threatened reptiles (Borgelt et al., 2022; Caetano et al., 2022). A prediction of higher-than-average risk was also made for reptile species that have not yet been evaluated (i.e., Not Evaluated (NE) category; Caetano et al., 2022) – which are usually small ranged (Meiri, 2016). Thirty-nine reptile species assessed as Data Deficient in 2009 have been reassessed as non-DD (IUCN, 2022). Of these, 15 (38.5 %) have moved from being Data Deficient to being categorized as threatened (3, 6 and 6 species in the Vulnerable, Endangered, and Critically Endangered categories, respectively; six others are now classified Near Threatened).

Species are more likely to be classified in a threatened category, or as Data Deficient, the more recently they were described: The percentage of threatened species out of all classifiable ones (i.e., those assessed as neither Data Deficient nor extinct; per decade) rises from ~10 % for species described until the 1860's, to over 35 % for species described since the 1990's (data from the IUCN redlist and description dates from Uetz, 2022). Similarly, the percentage of Data Deficient species out of all assessed, extant, species increases from zero in the 18th century (the first Data Deficient species, *Barkudia melanosticta* and *Rhinophis oxyrhynchus*, were described in 1801; description dates are from the reptile database, threat categories from the IUCN, 2022) to around 15 % by the turn of the 20th century, and to 24.2 % and 25.6 % for species described in the first and second decades of the 21st century –higher values than at any previous decade. In other words, the reptile species described after the beginning of the global reptile assessment (2004) are nearly twice as likely to have subsequently been assessed as either Data Deficient or threatened as species described earlier (Table 1).

The numbers of Data Deficient, threatened (Vulnerable, Endangered, Critically Endangered), and non-threatened (Least Concern, Near Threatened) species described before and after the GRA was initiated (in 2004). Differences between DD vs. non-DD between the periods and threatened vs. non-threatened (excluding Data Deficient and extinct) species between the periods are significant using Fisher Exact tests ($P < 0.00001$ in both cases).

Newly described species are also likely to have small ranges and thus more likely to be threatened than species described earlier (e.g., Meiri, 2016; Liu et al., 2022). We view this as suggesting that newly described, and Data Deficient species, are more likely to be threatened than a naïve prediction based on the overall proportion of threatened species would suggest. Predictive modelling approaches (e.g., Borgelt et al., 2022; Caetano et al., 2022) could be used to identify priority Data Deficient, and unassessed (including newly described) species for targeted study, and subsequent assessment. Currently, such models are all we have to approximate the conservation status of Data Deficient and Not Evaluated species, and to potentially prioritize the development of research and conservation actions for them. An even more helpful, but more cost- and time-intensive approach, will be to conduct dedicated field studies of the biogeography, ecology, natural history, and conservation needs of Data Deficient and newly described species to allow for standardised Red List assessment as non-Data Deficient.

3. Complete the second GRA within a decade

Given that reptiles are the final terrestrial vertebrate group to have a comprehensive global assessment, it is important that the next GRA is completed within the time frame recommended by the IUCN of every ten years. The second GRA is already underway and is prioritizing species whose assessments require updating (i.e., they were assessed prior to 2013). It is particularly vital to keep and increase GRA capacity to work through the backlog of out-of-date assessments. As of November 2022, 1920 amphibian species assessments (although the completion of the second Global Amphibian Assessment is imminent), and 2403 reptile species assessments, are listed as "need updating", compared with only 70 mammal species and zero bird species (Fig. 1). A total of 3200 species of reptiles (32 % of assessed species; according to the taxonomy of the Reptile Database; Uetz, 2022) were assessed in 2012 or earlier. To accomplish the task of completing Red List assessments on schedule will require global co-ordination of IUCN Specialist Groups, regional reptile experts, and conservation organizations (see Priority 7), and directed dedicated funding and resources.

4. Recognize challenges posed by the dynamic nature of reptile taxonomy

Reptile taxonomy, like amphibian taxonomy, is highly dynamic, with new species frequently described (e.g., Chapple et al., 2021; Melville et al., 2021; Tolley et al., 2022; Venegas et al., 2022; Bowles, in press). Recognized reptile species numbers have increased by 19 % since 2014, (~11,838 vs. 9952) making the Reptilia the largest tetrapod class in terms of species numbers (Fig. 2). Given that reptiles are described at faster rates than birds and mammals (Fig. 2), and that newly described species are often considered threatened, reptiles (and amphibians) may face a higher extinction risk than is currently acknowledged. This taxonomic upheaval is not only the result of new species discoveries. In fact, 35 % of the ~3500 new species of reptiles recognized since the GRA began in 2004 represent taxonomic 'splits' (Timrat Laniado, unpublished), including newly defined (including cryptic) species, revalidation of synonyms, and elevation of subspecies to species status. While there is much debate on how such taxonomic changes should be treated in terms of conservation (e.g., Garnett and Christidis, 2017; Raposo et al., 2017), the Red List is explicitly not a taxonomic source and has no remit to make taxonomic decisions. Specialist Groups responsible for Red List assessments curate their taxonomic group's species lists and may sometimes reject proposed taxonomic changes. That said, the Red List objective is to assess the extinction risk of all species, however defined, without claiming to know whether species need to be split, lumped, or maintained as the status quo. Splits recognize more species that need to be assessed, but also requires for new assessments of the 'parent' species (Chapple et al., 2021). The IUCN assessments of species that were split after being assessed often become instantly obsolete. Unfortunately, over 40 % of the reptile species that were split since 2004 were assessed prior to them being split (T. Laniado, unpublished data, 2022), which potentially undermines their current assessments.

There are important conservation implications of taxonomic reorganization. Following splits, 'parent' species will naturally have fewer subpopulations, fewer individuals, and smaller ranges. Further, range

Table 1
Data deficiency and threat for species described before, and after the onset of the Global Reptile Assessment.

	Described before the GRA started (pre 2004)	Described after start of the GRA (post 2003)
Data Deficient	1079 (13 %)	364 (25 %)
Threatened	1407 (17 %)	394 (27 %)
Not-threatened	6010 (71 %)	705 (48 %)

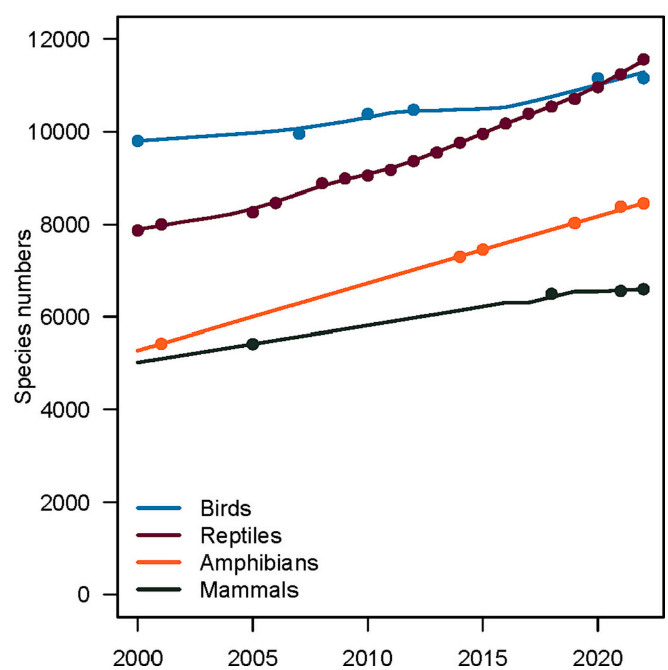

Fig. 2. Trends in number of species described for land-vertebrate classes in the 21st century. Mammals (green; data from Wilson and Reeder, 2005, Burgin et al., 2018, the American Society of Mammalogists, https://www.mammaldiversity.org/, and https://www.mammaldiversity.org/, version 1.9), amphibians (orange; data from Darrel frost, pers. comm. to Shai Meiri, 12.08.2015, https://amphibiaweb.org/, and https://amphibiansoftheworld.amnh.org/), reptiles (purple; data from different versions of the Reptile Database; Uetz, 2022) and birds (light blue; data from BirdLife International versions 0 and 6, Gill and Wright, 2006, HBW-BirdLife List of Birds v5 & v6). Points represent known class numbers in a particular year and lines are fit to a loess regression ($f = 0.3$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

overlap with protected areas could be smaller, while threats may occur over a higher proportion of the distribution. Finally, existing conservation measures might apply to only some of the species recognized after the split. Thus, re-assessments of species that were split subsequent to their original assessments are likely to identify that they are more threatened (potentially resulting in up-listing), but rarely that they are less threatened (potentially resulting in down-listing). A preliminary analysis (T. Laniado, unpublished data, 2022) shows that hundreds of reptile species have been split into two or more species rendering the original parent species assessments in urgent need of update given that their ranges that are small enough to trigger a review of Red List status under Criterion B – should threatening processes exist.

Here we outline two specific cases where taxonomic splits have been followed by new listing assessments. The first is the Philippine skink, *Parvoscincus decipiens,* which was split in 2013 to comprise eight species (Linkem and Brown, 2013). None of the seven newly recognized species were assessed in the first GRA (Cox et al., 2022), as the split occurred after the assessments for the region were completed in 2008. The current published assessment for *P. decipiens* was conducted in 2007 – as Least Concern. Instead of being widespread throughout the island of Luzon, the new concept of this species is now considered a narrow-ranged endemic (Linkem and Brown, 2013). A re-assessment for *P. decipiens* underway suggests that some of the seven newly described species are threatened or Data Deficient. The second example is *Tympanocryptis pinguicolla*, an Australian agamid associated with imperilled grasslands. This species was formerly considered widespread but was listed as Endangered when assessed in 2017 (Melville et al., 2018). The species was subsequently split into three species (Melville et al., 2019). At present, *T. pinguicolla* (sensu stricto) is considered possibly extinct (Garnett et al., 2022), but will soon be listed under Australian legislation as Critically Endangered. The last sighting of this earless dragon species, restricted to what was at the time the outskirts of the city of Melbourne, was in 1969 (Melville et al., 2019). Indeed, based on expert elicitation, the two species split off *T. pinguicolla*, *T. mccartneyi* (Bathurst grassland earless dragon), and *T. osbornei* (Monaro grassland earless dragon), are considered Australia's 5th and 27th most threatened squamate species ranked on a timeframe to extinction (Geyle et al., 2021).

5. Diversify approaches to measuring Red List criteria

An interesting result of the GRA is the difference in the conservation status between turtles and crocodiles, and of squamates (Cox et al., 2022). Essentially, Testudines (turtles, tortoises, and terrapins, hereafter ‘turtles’) and crocodilians were recognized as more threatened (57.9 % and 50.0 % of species, respectively) than squamates (19.6 %; Cox et al., 2022). To a large extent, this probably reflects that many turtles and crocodiles inhabit freshwater systems, which have been heavily degraded by pollution, development, desiccation, and water abstraction (He et al., 2019; Almond et al., 2020). Crocodiles and turtles are also much larger, on average, than squamates (Meiri et al., 2021) and have often been used as a source of food and skins, resulting population declines and some species extinctions (Slavenko et al., 2016; Cox et al., 2022). Criterion A is frequently applicable for many turtles and crocodilians, based on a “Population reduction (measured over the longer of 10 years or 3 generations, whichever is longer)” (IUCN, 2012). Thus, reductions need to be evaluated over longer periods for turtles and crocodiles (which, being longer living, have longer generation times; Stark et al., 2018) than for most squamates. Thus even given similar rates of population declines, the threshold for population reduction needed to qualify for any threat status is less likely to be reached for squamates with short generation times. Thus, Criterion A can less frequently be invoked for squamates even if we know they are declining at similar rates to other taxa. During the first GRA very limited data on squamate life history were collected for many squamates and a three-generation period was widely assumed to be lower than, or equal to, 10 years. For a number of these species this is likely to have been unrealistically short.

Some differences in the threat status between turtles, crocodilians, and squamates may also be due to squamates typically being less well studied, meaning that data on population sizes and rates of population decline are less frequently unavailable. For example, all threatened crocodilian species are listed under Criterion A (population size reduction), and 90.5 % of threatened turtle species are listed under either Criterion A or Criterion C (small population sizes and declines). Fewer than 15 % of turtle species are listed under Criterion B (small geographic range, and fragmented habitat or few locations, and decline; potentially because criteria A and C trigger a higher threat category), only 9.5 % of them exclusively so (Fig. 3). These figures are strikingly different for squamates: 93 % of threatened species (1834 of 1974) are listed under either Criteria B and/or D2 (small population and a plausible future threat); 90 % of them (1784 species) exclusively so (Fig. 3) but only 7.7 % under Criterion A and 1.2 % under Criterion C. The general lack of monitoring data for squamates mean we simply don't know how small populations are, or how fast they are declining (Tingley et al., 2016).

Overall, the threat status of the comparatively well-studied crocodilians and turtles has been evaluated from population trend data or inferences. Squamate (~96.7 % of reptile species) population sizes, and population decline estimates, are rarely known or inferred and assessors were reluctant to apply Criterion A because of the difficulty of quantifying rates of decline (even though ‘suspected’ data can be used). Therefore squamates, with their small range sizes (Roll et al., 2017), have mostly been evaluated based on the size and dynamics (decline in extent, occupancy, or habitat quality) of their geographic range. We suspect that some wide-ranging squamate species would likely qualify as threatened under Criterion A if their population declines could be reliably estimated – but long-term census data on population sizes and declines (that exist for many bird, large mammal, crocodile, and turtle species) are generally unavailable for squamates. This also affects other global analyses of reptile status and trends (e.g., see Saha et al., 2018 for lack of squamate population data in the Living Planet Database). Under Criterion B, only species with small ranges (at most 20,000 km^2 extent of occurrence or 2000 km^2 area of occupancy) can qualify as threatened. Thus, wider-ranging squamates cannot be evaluated as threatened under any criterion even if their populations decline due to trade, invasive species, disease, climate change, and pollution, unless rates of decline can be derived from proxy data. For example, when habitat loss is potentially severe and rapid it can be used to list species as threatened

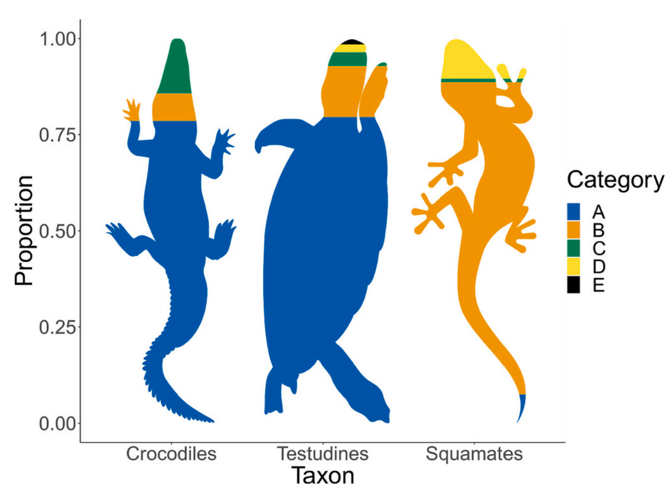

Fig. 3. IUCN Red List criteria applied to crocodiles, turtles, and squamates. The height of the colour column corresponds to the proportion of species listed under different criteria. Species that were classified according to multiple criteria were counted toward each. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

under Criterion A (e.g., by using remote-sensing data to estimate range changes by measuring the extent of suitable habitat across periods). This has been challenging for many squamates due both to data limitations (especially for older assessments dating to a period before time series of land cover change over relevant scales from remote sensing data were widely available) and typically short (perceived) generation times.

6. Improve our knowledge of threats to reptiles

One key consequence of the lack of research on most reptile species (tuatara and marine turtles are notable exceptions, e.g., Cree, 2014; Donaldson et al., 2016), and the fact that most species have been assessed relatively recently, is the current absence of long-term data with which to accurately assess historical changes to distribution and population trends. This restricts the ability to identify, and subsequently quantify, threats that most impact reptile species. Consequently, our limited knowledge on threats to species means that the conservation status of reptiles in many regions may be worse than is currently realised (Tingley et al., 2019; Chapple et al., 2021). Here, we outline three examples of how we may have underestimated the true plight of reptiles globally:

(i) Extremely small ranged species: Over 1750 reptile species, more than one in seven, are only known from tiny ranges (extent of occurrence <100 km^2; Meiri et al., 2018; Barki et al., submitted). These species are often less well known than more wide-ranging ones, and many have not been seen, let alone studied, in decades (Meiri et al., 2018). Consequently, we have little long-term data, or knowledge of the key threats, for most of them. Species with extremely small ranges can be listed as threatened under Criterion B if they are also in decline. However, for many species, failure to document evidence for a continuing decline (in the species range; extent and/or quality of habitat; number of subpopulations, locations, or number of mature individuals) will lead to them not qualifying for a threatened listing under the IUCN Red List guidelines. >160 reptile species are currently classified as Least Concern, despite being known only from their original description and not recorded again thereafter (Meiri et al., 2018; Barki et al., submitted). Some of these species were not seen for >50 years (Martin et al., 2022). Because they are not well enough known to demonstrate declines, a Least Concern listing could be technically correct according to the Red List guidelines, and typically this approach is taken with species known only from areas which may not have been revisited and where no threats are believed to be active. Improved data, however, may reveal novel or previously unrecognised threats that could warrant a threatened status under Criteria B, C or even D. Some Tepui-dwelling species, for example, were listed as Least Concern because they typically occur far from any plausible direct human impacts. They might, however, well be at greater immediate risk from factors such as climate change than was recognized when these species were first assessed a decade ago. Crucially for species with tiny ranges, adherence to two sub-criteria is required for classification of a species as threatened. The lack of knowledge on multiple sub-criteria prevents a listing as anything other than Data Deficient or Least Concern. Our knowledge of these species' natural history and ecology, hence of potential direct threats (rather than threats to their habitat), is rudimentary at best – and can often not be used to assign a threat category. Thus their assessments may prove to be conservative.

A further 450 reptile species known only from their original description are classified as Data Deficient, and these have a high likelihood of being threatened (Gumbs et al., 2020, Caetano et al., 2022, and see above). In many cases, the original descriptions are of specimens collected several decades ago (Meiri et al., 2018; Barki et al., submitted), and some species may be already extinct. Other species not recorded for decades were once considered widespread (e.g., the snake *Psammophis jallae* has been recorded only five times since the year 2000 and has not been recorded in South Africa since the 1980s; Krystal Tolley, unpublished data 2022). Thus, the second GRA should focus on identifying priorities for targeted monitoring of the smallest-ranged species (Meiri et al., 2018), as well as on species with no recent records (Martin et al., 2022).

(ii) Incorporate the threat of climate change: Although habitat loss, degradation, and fragmentation remain the primary threats to vertebrates, the impact of climate change has generally been left unaddressed in IUCN Red List assessments (Harfoot et al., 2021). This is because climate change impacts can be difficult to quantify (see Akçakaya et al., 2006; Foden and Young, 2016; IUCN Standards and Petitions Committee, 2019), and (for reptiles) have largely been considered to relate to future time-frames that are longer than the 10-year or three-generation time-frame used in Red Listing. Further, evaluation of the threats posed by climate change, such as sex ratio skews and subsequent population declines, require detailed study to quantify the potential effects for individual species or populations (e.g., see Mitchell and Janzen, 2010; 2012 for the tuatara). Finally, focus on recording proximate drivers of declines, and thus cases where climate change is, for example, increasing the prevalence of detrimental invasive species or diseases, it will often not be recorded in the assessment coding scheme (though it may be recognized in an assessment's text). This may lead to the misconception that climate change is not a key threat for some taxa (Caro et al., 2022), but it potentially simply reflects limited exploration of climate change impacts on reptile taxa to provide an evidence base for the application of IUCN Red List criteria. This is surprisingly given high profile studies of squamates that point to recent and widespread population and species extinctions linked to climate change (Sinervo et al., 2010). Climate change should be incorporated more fully during the second GRA, as the current and future impacts of climate change on species, their ranges, and the quality of their habitat, become better understood.

Worryingly, we have evidence and reasoning to suggest that reptiles maybe be greatly affected by future climatic changes, particularly as their foraging activities become increasingly constrained by high temperatures (Sinervo et al., 2010; Huey and Kingsolver, 2019). Further, reptiles have, on average, smaller ranges than mammals and birds (Roll et al., 2017) and thus will most likely have less potential for climatic refugia within their current ranges. Reptiles also have a high proportion of island and montane endemics (Roll et al., 2017) that will unlikely be able to track suitable climatic niches as these will shift away from their current ranges (Miller et al., 2012). Some recent evidence supports this notion, as there are indications that regions with high reptile phylogenetic endemism will suffer greater temperature and precipitation change velocity compared to other regions (Murali et al., 2021). Initial explorations of the effects of extreme climatic events also identify reptiles as a particularly sensitive taxon (Murali et al., 2023).

(iii) Continue monitoring use and trade. Removal of reptiles from the wild, for commercial or subsistence use, is fully incorporated in current IUCN Red List assessments – but could still be underestimated (e.g., see Marsh et al., 2022). Of all the threats to reptiles, trade is one of the ones that has had the most serious consideration in Red List assessments, because it is very widely perceived to be a serious impact. Assessors provided the 'Use and Trade' information for 1629 reptile species 329 of which are threatened (3.2 % of those assessed - but 30.8 % of all turtle species; Cox et al., 2022). Marshall et al. (2020), however, estimated that 3943 reptile species are being traded (mostly via collecting in the wild). If this figure is correct it represents over twice as many species as those for which information is given in the IUCN Red List assessments (potentially in part because many traded species have not yet been assessed). Most reptile trade is not regulated by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES: https://cites.org/eng). We caution against assuming that marketing a reptile for sale means trade threatens the species (Challender et al., 2022). Indeed, assessments often note that while there is collecting from the wild, its levels do not merit a threat category. In some cases, however, newly discovered small-ranged species are specifically targeted by traders (Auliya et al., 2016; Mialon et al., 2022). We recommend that assessors keep paying attention to potential, and realistic, threats from trade and provide the recommended Use and Trade information in the Red List assessments (Marsh et al., 2022).

(iv) Increase use of projected declines. Although there are many opportunities to incorporate projected declines into conservation assessments for reptiles (i.e., Criterion A3 and A4, Criterion B (b) and C1 and C2), the use of such projections in conservation assessments has been limited. This is because 'projected' declines require the same level of evidence as 'suspected' or 'inferred' data. However, we are in the midst of increasing pressures on our natural ecosystems and major population declines of the associated biodiversity (Murali et al., 2022b). These pressures include, for example, agents such as land use change (Newbold et al., 2015) and climate change (Trisos et al., 2020; see Priority 6(iii)). This means that even species that are not known to be declining today, or have not reached rates which trigger threatened status, are already, or will soon become, more threatened than their current IUCN Red List status implies. The overall smaller geographic ranges of reptiles (and amphibians) compared to mammals and, especially, birds, may further mean that even localized threats could quickly lead species, and even entire reptile communities, to decline toward extinction (e.g., as has occurred recently on Christmas Island in the Indian Ocean due to invasive species; Emery et al., 2021). Thus, in the second GRA there is much scope to increase the use of analyses that project declines in population size, or in habitat quality or extent, over appropriate time-scales for Red List assessment (e.g., Legge et al., 2022).

One way to ameliorate the situation is for herpetological societies and funders the world-over to prioritize and incentivize programs for field studies that aim to estimate population size and trend data for squamate species (mainly Not Evaluated and Data Deficient species). Collaborations between institutions the world-over (but considering good practices in collaboration for funding; Escobar Álvarez et al., 2021) could be key to close such knowledge gaps.

7. Enhance capacity for global reptile assessment

Global assessments of entire species groups, such as the Global Reptile Assessment, rely on adequate and dedicated funding and capacity to be delivered in timely fashion. For example, BirdLife coordinates the bird assessment effort by linking with the relevant IUCN Species Survival Commission (SSC) Specialist Groups, providing additional input from their expert network and coordinating processing and submission of assessments. The Global Mammal Assessment (https://globalmammal.org/) oversees the assessment of mammals at regular intervals and connects to the IUCN SSC mammal Specialist Groups to produce and publish assessments. Specialist groups played a limited role in the first GRA (due to a lack of such groups for many reptile taxa), with the IUCN-Conservation International Biodiversity Assessment Unit providing the overarching coordination for the assessments through a series of 48 regional workshops to gain perspectives of local scientists familiar with species under assessment - a time and resource intensive assessment process. Using the model from mammals and birds, and linking to the many established reptile Specialist Groups, the second GRA could provide much needed support for concluding the next round of assessments. Strong coordination and communication between the GRA leadership and the existing and newly emerging reptile Specialist Groups could greatly improve capacity for the second GRA. The recent establishment of the Global Center for Species Survival, a joint venture between the Indianapolis Zoo and the IUCN Species Survival Commission, is a positive development in this area. The center employs a Reptile and Amphibian Conservation Coordinator and should facilitate communication between all reptile specialist groups, as well as drive the development of additional reptile Specialist Groups. For example, the Gekkota (geckos and pygopodids) is one of the largest squamate clades (> 2250 species, of which 1708 are currently assessed for the Red List), yet no specialist group exists for this group. At the same time, establishment of regional or national centers for Species Survival, which provide staff time to IUCN SSC efforts such as Red List assessments, will aid assessment throughput if they also focused on reptiles.

Future workshops should incorporate knowledge from both local experts (both within and outside the IUCN SSC Specialist Group network) and IUCN SSC (via a coordination body such as that for the first GRA). The former can provide pre-workshop data and insights gained in the field regarding natural history, ecology, and conservation, while the globally spread latter provides coordination and broad expertise in the post-workshop dissemination and publication of results. Such schemes should be agreed upon prior to the regional workshops (e.g., Beck et al., 2019; Maestre and Eisenhauer, 2019) and can generate greatly beneficial interactions for advancing knowledge of reptile species and their conservation in the field.

Finally, increasing collaboration and coordination between the GRA and countries that use similar listing criteria under their environmental legislation (e.g., Australia and Brazil, e.g., Raimondo et al., 2022) could greatly enhance the currency of global reptile assessments, and avoid duplication of effort and expert's time. National species specialist groups, a more recent SSC initiative comprised of experts across all taxa from the same country, may be a useful partner to provide country-specific information to the GRA.

8. Conclusions

The recommendations outlined here should not detract from the enormous effort and the immense value of the first GRA (Cox et al., 2022). Now that a GRA is complete, reptiles can finally take their place at the "high table" of global conservation planning. Global and local analyses of conservation needs and priorities focusing on birds, mammals and amphibians, but rarely Reptilia – the largest terrestrial vertebrate class – should now be a thing of the past. But we should not rest on our laurels. The incredible rate of new reptile descriptions, of over 200 more species recognized yearly over the last decade (Fig. 2), nearly 240 species a year in the last five years, makes the task somewhat Sisyphean, but also immensely important. The second GRA should focus on the seven priorities that we have identified, revisiting old assessments, taking more types of data into account, flagging species with obsolete assessments due to age or taxonomic changes and more regularly invoking projected declines in reptile population sizes. Further, advances in automated, machine-learning based methods now exist to model extinction risk. These take available projections of threats such as future climate change and couple them with high resolution, accurate maps of species distributions (Roll et al., 2017; Cazalis et al., 2022; Caetano et al., 2022). The results of such models can inform assessments of newly described species, species with dated assessments, or those with changed taxonomies. Since Red List assessments in their very nature are dynamic, we should view the first GRA as a beginning, rather than as a long-awaited endpoint.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data used are from publicly available sources which we cite

Acknowledgements

This work has been funded by the Israel Science Foundation Grant Num. 406/19 to SM & UR (https://www.isf.org.il/). David Chapple was supported by a grant from the Australian Research Council (FT200100108). We thank Francesco Ficetola and an anonymous referee for excellent comments on a previous draft of this work

References

Akçakaya, H.R., Butchart, S.H., Mace, G.M., Stuart, S.N., Hilton-Taylor, C., 2006. Use and misuse of the IUCN red list criteria in projecting climate change impacts on biodiversity. Glob. Chang. Biol. 12 (11), 2037–2043.

Almond, R.E., Grooten, M., Peterson, T., 2020. Living Planet Report 2020-Bending the Curve of Biodiversity Loss. World Wildlife Fund.

Auliya, M., Altherr, S., Ariano-Sanchez, D., Baard, E.H., Brown, C., Brown, R.M., Cantu, J.C., Gentile, G., Gildenhuys, P., Henningheim, E., Hintzmann, J., 2016. Trade in live reptiles, its impact on wild populations, and the role of the european market. Biol. Conserv. 204, 103–119.

Goni Barki, Gopal Murali, Andrew Amey, Aaron M. Bauer, Rafe M. Brown, Gabriel H.D. O. Caetano, R. Chaitanya, Laurent Chirio, Diego F. Cisneros-Heredia, Patrick Couper, Indraneil Das, Tiffany M. Doan, Andrew M. Durso, Ryan Ellis, Harith Farooq, Frank Glaw, Lee Grismer, Peng Guo, Marinus S. Hoogmoed, Luciano J. Avila, Fred Kraus, Matthew LeBreton, Marcio Martins, Zoltan T. Nagy, Truong Q. Nguyen, Cristiano D. C. Nogueira, Paulo Passos, Olivier S.G. Pauwels, Vivek P. Cyriac, Marco A. Ribeiro-Junior, Glenn M. Shea, Omar Torres-Carvajal, Jean-François Trape, Peter Uetz, Thomas Ziegler, Anna Zimin, Uri Roll & Shai Meiri. Rare snakes are common: Patterns and attributes of the world's smallest-ranging snakes. Conservation Letters, submitted.

Beck, P., Quirós, R., Johnson, C.E., Wasserman, M.D., 2019. Biological research stations as central nodes in promoting north-south collaborative networks for teaching and research. Curr. Opin. Environ. Sustain. 39, 31–38.

BirdLife International, 2000. Cambridge and Barcelona: BirdLife International and Lynx Edicions. In: Threatened birds of the world, 852 pp.

BirdLife International, 2004c. Threatened Birds of the World 2004 [CD-ROM]. BirdLife International, Cambridge.

Bland, L.M., Böhm, M., 2016. Overcoming data deficiency in reptiles. Biol. Conserv. 204A, 16–22.

Bohm, M., Collen, B., Baillie, J. E. M., Bowles, P., Chanson, J., Cox, N., Hammerson, G., Hoffmann, M., Livingstone, S. R., Ram, M., Rhodin, A. G. J., Stuart, S. N., van Dijk, P. P., Young, B. E., Afuang, L. E., Aghasyan, A., Garcia, A., Aguilar, C., Ajtic, R., Akarsu, F., Alencar, L. R. V., Allison, A., Ananjeva, N., Anderson, S., Andren, C., Ariano-Sanchez, D., Arredondo, J. C., Auliya, M., Austin, C. C., Avci, A., Baker, P. J., Barreto-Lima, A. F., Barrio-Amoros, C. L., Basu , D., Bates, M. F., Batistella, A., Bauer, A., Bennett, D., Bohme, W., Broadley, D., Brown, R., Burgess, J., Captain, A., Carreira, S., Castaneda, M. R., Castro, F., Catenazzi, A., Cedeno-Vazquez, J. R., Chapple, D. G., Cheylan, M., Cisneros-Heredia, D. F., Cogalniceanu, D., Cogger, H., Corti, C., Costa, G. C., Couper, P. J., Courtney, T., Crnobrnja-isailovic, J., Crochet, P [A., Crother, B., Cruz, F., Daltry, J. C., Ranjit Daniels, R. J., Das, I., de Silva, A., Diesmos, A. C., Dirksen, L., Doan, T. M., Dodd, K., Doody, S., Dorcas, M. E., de Barros Filho, J. D., Egan, V. T., El Mouden, E. H., Embert, D., Espinoza, R. E., Fallabrino, A., Feng, X., Feng, Z-J., Fitzgerald, L., Flores-Villela, O., Franca, F. G. R., Frost, D., Gadsden, H., Gamble, T., Ganesh, S. R., Garcia, M. A., Garcia-Perez, J. E., Gatus, J., Gaulke, M., Geniez, P., Georges, A., Gerlach, J., Goldberg, S., Gonzalez, J-C. T., Gower, D. J., Grant, T., Greenbaum, E., Grieco, C., Guo, P., Hamilton, A. M., Hare, K., Hedges, S. B., Heideman, N., Hilton-Taylor, C., Hitchmough, R., Hollingsworth, B., Hutchinson, M., Ineich, I., iverson, J., Jaksic, F. M., Jenkins, R., Joger, U., Jose, R., Kaska, Y., Kaya, U., Keogh, J. S., Kohler, G., Kuchling, G., Kumlutas, Y., Kwet, A., La Marca, E., Lamar, W., Lane, A., Lardner, B., Latta, C., Latta, C., Lau, M., Lavin, P., Lawson, D., LeBreton, M., Lehr, E., Limpus, D., Lipczynski, N., Lobo, A. S., Lopez-Luna, M. A., Luiselli, L., Lukoschek, V., Lundberg, M., Lymberakis, P., Macey, R., Magnusson, W. E., Mahler, D. L., Malhotra, A., Mariaux, J., Maritz, B., Marques, O. A. V., Marquez, R., Martins, M., Masterson, G., Mateo, J. A., Mathew, R., Mathews, N., Mayer, G., McCranie, J. R., Measey, G. J., Mendoza-Quijano, F., Menegon, M., Metrailler, S., Milton, D. A., Montgomery, C., Morato, S. A. A., Mott, T., Munoz-Alonso, A., Murphy, J., Nguyen, T. Q., Nilson, G., Nogueira, C., Nunez, H., Orlov, N., Ota, H., Ottenwalder, J., Papenfuss, T., Pasachnik, S., Passos, P., Pauwels, O. S. G., Perez-Buitrago, N., Perez-Mellado, V., Pianka, E. R., Pleguezuelos, J., Pollock, C., Ponce-Campos, P., Powell, R., Pupin, F., Quintero Diaz, G. E., Radder, R., Ramer, J., Rasmussen, A. R., Raxworthy, C., Reynolds, R., Richman, N., Rico, E. L., Riservato, E., Rivas, G., da Rocha, P. L. B., Rodel, M-O., Schettino, L. R., Roosenburg, W. M., Ross, J. P., Sadek, R., Sanders, K., Santos-Barrera, G., Schleich, H. H., Schmidt, B. R., Schmitz, A., Sharifi, M., Shea, G., Shi, H-T., Shine, R., Sindaco, R., Slimani, T., Somaweera, R., Spawls, S., Stafford, P., Stuebing, R., Sweet, S., Sy, E., Temple, H. J., Tognelli, M. F., Tolley, K., Tolson, P. J., Tuniyev, B., Tuniyev, S., Uzum, N., van Buurt, G., Van Sluys, M., Velasco, A., Vences, M., Vesely, M., Vinke, S., Vinke, T., Vogel, G., Vogrin, M., Vogt, R. C., Wearn, O. R., Werner, Y. L., Whiting, M. J., Wiewandt, T., Wilkinson, J., Wilson, B., Wren, S., Zamin, T., Zhou, K. and Zug, G. 2013. The conservation status of the world's reptiles. Biological Conservation 157: 372-385.

Borgelt, J., Dorber, M., Hoiberg, M.A., Verones, F., 2022. More than half of data deficient species predicted to be threatened by extinction. Commun. Biol. 5, 679.

Bowles, in press, P. Bowles in press Chapter 7 – Reptiles. In: N. Maclean (ed.), The Living Planet. Cambridge University Press, Cambridge, UK.

Brondizio, E.S., Settele, J., Díaz, S., Ngo, H.T., 2019. Global assessment report on biodiversity and ecosystem services of the intergovernmental science-policy platform on biodiversity and ecosystem services (IPBES Secretariat 2019). Available from: https://ipbes.net/global-assessment.

Burgin, C.J., Colella, J.P., Kahn, P.L., Upham, N.S., 2018. How many species of mammals are there? J. Mammal. 99, 1–11.

Butchart, S.H., Stattersfield, A.J., Bennun, L.A., Shutes, S.M., Akçakaya, H.R., Baillie, J. E., Stuart, S.N., Hilton-Taylor, C., Mace, G.M., 2004. Measuring global trends in the status of biodiversity: red list indices for birds. PLoS Biol. 2, e383 https://doi.org/10.1371/journal.pbio.0020383.

Caetano, G.O.H., Chapple, D.G., Grenyer, R., Raz, T., Rosenblatt, J., Tingley, R., Böhm, M., Meiri, S., Roll, U., 2022. Automated assessment reveals extinction risk of reptiles is widely underestimated across space and phylogeny. PLoS Biol. 20, e3001544 https://doi.org/10.1371/journal.pbio.3001544.

Caro, T., Rowe, Z., Berger, J., Wholey, P., Dobson, A., 2022. An inconvenient misconception: climate change is not the principal driver of biodiversity loss. Conserv. Lett. 15, e12868.

Cazalis, V., Di Marco, M., Butchart, S.H.M., Akçakaya, H.R., González-Suárez, M., Meyer, C., Clausnitzer, V., Böhm, M., Zizka, A., Cardoso, P., Schipper, A.M., Bachman, S.P., Young, B.E., Hoffmann, M., Benítez-López, A., Lucas, P.M., Pettorelli, N., Patoine, G., Pacifici, M., Jörger-Hickfang, T., Brooks, T.M., Rondinini, C., Hill, S.L.L., Visconti, P., Santini, L., 2022. Bridging the research-implementation gap in IUCN red list assessments. Trends Ecol. Evol. 37, 359–370. https://doi.org/10.1016/j.tree.2021.12.002.

Challender, D.W., Brockington, D., Hinsley, A., Hoffmann, M., Kolby, J.E., Massé, F., Natusch, D.J., Oldfield, T.E., Outhwaite, W., 't Sas-Rolfes, M., Milner-Gulland, E.J., 2022. Mischaracterizing wildlife trade and its impacts may mislead policy processes. Conserv. Lett. 15 (1), e12832.

Chapple, D.G., Roll, U., Böhm, M., Aguilar, R., Amey, A.P., Austin, C.C., Baling, M., Barley, A.J., Bates, M.F., Bauer, A.M., Blackburn, D.G., Bowles, P., Brown, R.M., Candramouli, S.R., Chirio, L., Cogger, H., Colli, G.R., Conradie, W., Couper, P.J., Cowan, M.A., Craig, M.D., Das, I., Datta-Roy, A., Dickman, C.R., Ellis, R.J., Fenner, A.L., Ford, S., Ganesh, S.R., Gardner, M.G., Geissler, P., Gillespie, G.R., Glaw, F., Greenlees, M.J., Griffith, O.W., Grismer, L.L., Haines, M.L., Harris, D.J., Hedges, S.B., Hitchmough, R.A., Hoskin, C.J., Hutchinson, M.N., Ineich, I., Janssen, J., Johnston, G.R., Karin, B.R., Keogh, J.S., Kraus, F., LeBreton, M., Lymberakis, P., Masroor, R., McDonald, P.J., Mecke, S., Melville, J., Melzer, S., Michael, D.R., Miralles, A., Mitchell, N.J., Nelson, N.J., Nguyen, T.Q., Nogueira, C.D. C., Ota, H., Pafilis, P., Pauwels, O.S.G., Perera, A., Pincheira-Donoso, D., Reed, R.N., Ribeiro-Junior, M.A., Riley, J.L., Rocha, S., Rutherford, P.L., Sadlier, R.A., Shacham, B., Shea, G.M., Shine, R., Slavenko, A., Stow, A., Sumner, J., Tallowin, O.J. S., Teale, R., Torres-Carvajal, O., Trape, J.F., Uetz, P., Ukuwela, K.D.B., Valentine, L., Van Dyke, J.U., van Winkel, D., Vasconcelos, R., Vences, M., Wagner, P., Wapstra, E., While, G.M., Whiting, M.J., Whittington, C.M., Wilson, S., Ziegler, T., Tingley, R., Meiri, S., 2021. Conservation status of the world's skinks (Scincidae): taxonomic and geographic patterns in extinction risk. Biol. Conserv. 257, 109101 https://doi.org/10.1016/j.biocon.2021.109101.

Collar, N.J., Andrew, P., 1988. Birds to Watch: The ICBP World Checklist of Threatened Birds. ICBP and IUCN, Cambridge.

Collar, N.J., Crosby, M.J., Stattersfield, A.J., 1994. Birds to Watch 2: The World List of Threatened Birds. BirdLife International, Cambridge, 407 pp.

Cox, N., Young, B.E., Bowles, P., Fernandez, M., Marin, J., Rapacciuolo, G., Böhm, M., Brooks, T.M., Hedges, S.B., Hilton-Taylor, C., Hoffmann, M., Jenkins, R.K.B., Tognelli, M.F., Alexander, G.J., Allison, A., Ananjeva, N.B., Auliya, M., Avila, L.J., Chapple, D.G., Cisneros-Heredia, D.F., Cogger, H.G., Colli, G.R., de Silva, A., Eisemberg, C.C., Els, J., Fong, A.G., Grant, T.D., Hitchmough, R.A., Iskandar, D.T., Kidera, N., Martins, M., Meiri, S., Mitchell, N.J., Molur, S., Nogueira, C.C., Ortiz, J. C., Penner, J., Rhodin, A.G.J., Rivas, G., Rödel, M.-O., Roll, U., Sanders, K.L., Santos-Barrera, G., Shea, G.M., Spawls, S., Stuart, B.L., Tolley, K.A., Trape, J.-F., Vidal, M. A., Wagner, P., Wallace, B.P., Xie, Y., 2022. Global reptile assessment shows commonality of tetrapod conservation needs. Nature 605, 285–290.

Cree, A., 2014. Tuatara: Biology and Conservation of a Venerable Survivor, 2014. Canterbury University Press, Christchurch, 584 pp.

Donaldson, M.R., Burnett, N.J., Braun, D.C., Suski, C.D., Hinch, S.G., Cooke, S.J., Kerr, J. T., 2016. Taxonomic bias and international biodiversity conservation research. Facets 1, 105–113.

Emery, J.P., Mitchell, N.J., Cogger, H., Agius, J., Andrew, P., Arnall, S., Detto, T., Driscoll, D.A., Flakus, S., Green, P., Harlow, P., 2021. The lost lizards of Christmas Island: a retrospective assessment of factors driving the collapse of a native reptile community. Conserv. Sci. Pract. 3, e358.

Escobar Álvarez, S.N., Drake, W.P., Evans, L., Myers, E.R., 2021. Funders, diversifyresearch grant awards. Science 374, 1063–1064.

Foden, W.B., Young, B.E., 2016. IUCN SSC Guidelines for Assessing Species' Vulnerability to Climate Change. Version 1.0. Occasional Paper of the IUCN Species Survival Commission No. 59. Cambridge, UK and Gland, Switzerland: IUCN Species Survival Commission x+114pp.

Garnett, S.T., Christidis, L., 2017. Taxonomy anarchy hampers conservation. Nature 546, 25–27.

Garnett, S.T., Hayward-Brown, B.K., Kopf, R.K., Woinarski, J.C.Z., Cameron, K.A., Chapple, D.G., Copley, P., Fisher, A., Gillespie, G., Latch, P., Legge, S., Lintermans, M., Moorrees, A., Page, M., Renwick, J., Birrell, J., Kelly, D., Geyle, H. M., 2022. Australia's most imperilled vertebrates. Biol. Conserv. 270, 109561 https://doi.org/10.1016/j.biocon.2022.109561.

Geyle, H.M., Tingley, R., Amey, A., Cogger, H., Couper, P., Cowan, M., Craig, M.D., Doughty, P., Driscoll, D., Ellis, R., Emery, J.P., Fenner, A., Gardner, M.G., Garnett, S. T., Gillespie, G.R., Greenlees, M.J., Hoskin, C.J., Keogh, J.S., Lloyd, R., Melville, J., McDonald, P., Michael, D.R., Mitchell, N.J., Sanderson, C., Shea, G.M., Sumner, J., Wapstra, E., Woinarski, J.C.Z., Chapple, D.G., 2021. Reptiles on the brink: identifying the australian terrestrial snake and lizard species most at risk of extinction. Pac. Conserv. Biol. 27, 3–12. https://doi.org/10.1071/PC20033.

Gill, F., Wright, M., 2006. Birds of the World: Recommended English Names. Princeton University Press, Princeton NJ. Version 2.11 generated on 2012-01-02.

Global Mammal Assessment, 2022. https://globalmammal.org/. (Accessed 26 April 2022).

Grace, M.K., Akçakaya, H.R., Bennett, E.L., Brooks, T.M., Heath, A., Hedges, S., Hilton-Taylor, C., Hoffmann, M., Hochkirch, A., Jenkins, R., Keith, D.A., et al., 2021.

Testing a global standard for quantifying species recovery and assessing conservation impact. Conserv. Biol. 35, 1833–1849.

Gumbs, R., Gray, C., Bohm, M., Hoffmann, M., Grenyer, R., Jetz, W., Meiri, S., Roll, U., Owen, N., Rosindell, J., 2020. Global priorities for conservation of reptilian phylogenetic diversity in the face of human impacts. Nat. Commun. 11, 2616. https://doi.org/10.1038/s41467-020-16410-6.

Harfoot, M.B.J., Johnston, A., Balmford, A., Burgess, N.D., Butchart, S.H.M., Dias, M.P., Hazin, C., Hilton-Taylor, C., Hoffmann, M., Isaac, N.J.B., Iverson, L.L., Outhwaite, C. L., Viconti, P., Geldmann, J., 2021. Using the IUCN red list to map threats to terrestrial vertebrates at global scale. Nat. Ecol. Evol. 5, 1510–1519. https://doi.org/10.1038/s41559-021-01542-9.

Hayward, M.W., 2011. Using the IUCN red list to determine effective conservation strategies. Biodivers. Conserv. 20, 2563–2573.

He, F., Zarfl, C., Bremerich, V., David, J.N., Hogan, Z., Kalinkat, G., Tockner, K., Jähnig, S.C., 2019. The global decline of freshwater megafauna. Glob. Chang. Biol. 25, 3883–3892.

Huey, R.B., Kingsolver, J.G., 2019. Climate warming, resource availability, and the metabolic meltdown of ectotherms. Am. Nat. 194 (6), E140–E150.

IUCN, 2012. IUCN Red List Categories and Criteria: Version 3.1, Second edition. IUCN, Gland, Switzerland and Cambridge, UK. iv + 32pp.

IUCN, 2022. The IUCN red list of threatened species. Version 2021-3. https://www.iucnredlist.org.

IUCN SSC Amphibian Specialist Group, 2022. Global amphibian assessment 2. https://www.iucn-amphibians.org/red-listing/global-amphibian-assessment-2/#:~:text=To%20address%20this%2C%20in%202015,assessed%20for%20the%20first%20time. (Accessed 26 April 2022).

IUCN Standards and Petitions Committee, 2019. Guidelines for using the IUCN red list categories and criteria. Version 14. Prepared by the Standards and Petitions Committee. http://www.iucnredlist.org/documents/RedListGuidelines.pdf iv + 32pp.

Juslen, A., Hyvaerinen, E., Virtanen, L.K., 2013. Application of the red-list index at a national level for multiple species groups. Conserv. Biol. 27, 398–406.

Legge, S., Rumpff, L., Woinarski, J.C., Whiterod, N.S., Ward, M., Southwell, D.G., Zukowski, S., 2022. The conservation impacts of ecological disturbance: time-bound estimates of population loss and recovery for fauna affected by the 2019–2020 australian megafires. Glob. Ecol. Biogeogr. 31, 2085–2104.

Linkem, C.W., Brown, R.M., 2013. Systematic revision of the parvoscincus decipiens (Boulenger, 1894) complex of philippine forest skinks (Squamata: scincidae: Lygosominae) with descriptions of seven new species. Zootaxa 3700, 501–533.

Liu, J., Slik, F., Zheng, S., Lindenmayer, D.B., 2022. Undescribed species have higher extinction risk than known species. Conserv. Lett. 2022, e12876.

Maestre, F.T., Eisenhauer, N., 2019. Recommendations for establishing global collaborative networks in soil ecology. Soil Organ. 91 (3), 73.

Mair, L., Bennun, L.A., Brooks, T.M., et al., 2021. A metric for spatially explicit contributions to science-based species targets. Nat. Ecol. Evol. 5, 836–844. https://doi.org/10.1038/s41559-021-01432-0.

Marsh, S.M., Hoffmann, M., Burgess, N.D., Brooks, T.M., Challender, D.W., Cremona, P. J., Hilton-Taylor, C., de Micheaux, F.L., Lichtenstein, G., Roe, D., Böhm, M., 2022. Prevalence of sustainable and unsustainable use of wild species inferred from the IUCN red list of threatened species. Conserv. Biol. 36, e13844.

Marshall, B.M., Strine, C., Hughes, A.C., 2020. Thousands of reptile species threatened by under-regulated global trade. Nat. Commun. 11, 4738.

Martin, T.E., Bennett, G.C., Fairbairn, A., Mooers, A.O., 2022. 'Lost' taxa and their conservation implications. Anim. Conserv. https://doi.org/10.1111/acv.12788.

Meiri, S., 2016. Small, rare and trendy: traits and biogeography of lizards described in the 21st century. J. Zool. 299, 251–261. https://doi.org/10.1111/jzo.12356.

Meiri, S., Bauer, A.M., Allison, A., Castro-Herrera, F., Chirio, L., Colli, G.R., Das, I., Doan, T.M., Glaw, F., Grismer, L.L., Hoogmoed, M., Kraus, F., LeBreton, M., Meirte, D., Nagy, Z.T., Nogueira, C.C., Oliver, P., Pauwels, O.S.G., Pincheira-Donoso, D., Shea, G., Sindaco, R., Tallowin, O.J.S., Torres-Carvajal, O., Trape, J.-F., Uetz, P., Wagner, P., Wang, Y., Ziegler, T., Roll, U., 2018. Extinct, obscure or imaginary: the lizard species with the smallest ranges. Divers. Distrib. 24, 262–273. https://doi.org/10.1111/ddi.12678.

Meiri, S., Murali, G., Zimin, A., Shak, L., Itescu, Y., Caetano, G., Roll, U., 2021. Different solutions lead to similar life history traits across the great divides of the amniote tree of life. J. Biol. Res. (Thessaloniki) 28, 3. https://doi.org/10.1186/s40709-021-00134-9.

Melville, J., Hutchinson, M., Clemann, N., Robertson, P., Michael, D., 2018. Tympanocryptis pinguicolla. The IUCN Red List of Threatened Species 2018: e. T22579A83494675. https://doi.org/10.2305/IUCN.UK.2018-1.RLTS.T22579A83494675.en. (Accessed 26 April 2022).

Melville, J., Chaplin, K., Hutchinson, M., Sumner, J., Gruber, B., MacDonald, A.J., Sarre, S.D., 2019. Taxonomy and conservation of grassland earless dragons: new species and an assessment of the first possible extinction of a reptile on mainland Australia. R. Soc. Open Sci. 6, 190233.

Melville, J., Chapple, D.G., Keogh, J.S., Sumner, J., Amey, A., Bowles, P., Brennan, I.G., Couper, P., Donnellan, S.C., Doughty, P., Edwards, D.L., Ellis, R.J., Esquerre, D., Fenker, J., Gardner, M.G., Georges, A., Haines, M.L., Hoskin, C.J., Hutchinson, M., Moritz, C., Nenkivell, J., Oliver, P., Pavon-Vazquez, C.J., Pepper, M., Rabosky, D.L., Sanders, K., Shea, G., Singhal, S., Worthington Wilmer, J., Tingley, R., 2021. A return-on-investment approach for prioritization of rigorous taxonomic research needed to inform responses to the biodiversity crisis. PLoS Biol. 19, e3001210 https://doi.org/10.1371/journal.pbio.3001210.

Mialon, H.M., Klumpp, T., Williams, M.A., 2022. International trade and the survival of mammalian and reptilian species. Sci. Adv. 8, eabh3442.

Miller, K.A., Miller, H.C., Moore, J.A., Mitchell, N.J., Cree, A., Allendorf, F.W., Sarre, S. D., Keall, S.N., Nelson, N.J., 2012. Securing the demographic and genetic future of tuatara through assisted colonization. Conserv. Biol. 26 (5), 790–798.

Mitchell, N.J., Janzen, F.J., 2010. Temperature-dependent sex determination and contemporary climate change. Sex. Dev. 4, 129–140.

Murali, G., Gumbs, R., Meiri, S., Roll, U., 2021. Global determinants and conservation of evolutionary and geographic rarity in land vertebrates. Sci. Adv. 7, eabe5582.

Murali, G., Caetano, G.H.O., Barki, G., Meiri, S., Roll, U., 2022. Emphasizing declining populations in the living planet report. Nature 601, E20–E24.

Murali, G., Iwamura, T., Meiri, S., Roll, U., 2023. Future temperature extremes threaten land vertebrates. Nature. https://doi.org/10.1038/s41586-022-05606-z.

Newbold, T., Hudson, L.N., Hill, S.L.L., Contu, S., Lysenko, I., Senior, R.A., Borger, L., Bennett, D.J., Choimes, A., Collen, B., Day, J., De Palma, A., Diaz, S., Echeverria-Londono, S., Edgar, M.J., Feldman, A., Garon, M., Harrison., M.L.K., Alhusseini, T., Ingram, D.J., Itescu, Y., Kattge, J., Kemp, V., Kirkpatrick, L., Kleyer, M., Correia, D.L. P., Martin, C.D., Meiri, S., Novosolov, M., Pan, Y., Phillips, H.R.P., Purves, D.W., Robinson, A., Simpson, J., Tuck, S.L., Weiher, E., White, H.J., Ewers, R.M., Mace, G. M., Scharlemann, J.P.W., Purvis, A., 2015. Global effects of land use on local terrestrial biodiversity. Nature 520, 45–50. https://doi.org/10.1038/nature14324.

Raimondo, D., Young, B., Brooks, T.M., Cardoso, P., van der Colff, D., de Souza Dias, B.F., Vercillo, U., de Souza, E., Juslén, A., Hyvarinen, E., von Staden, L., Tolley, K., McGowan, P., 2022. Using red list indices to monitor extinction risk at national scales. Conserv. Sci. Pract., e12854

Raposo, M.A., Stopiglia, R., Brito, G.R.R., Bockmann, F.A., Kirwan, G.M., Gayon, J., Dubois, A., 2017. What really hampers taxonomy and conservation? A riposte to Garnett and christidis (2017). Zootaxa 4317, 179–184.

Renjifo, L.M., Amaya-Villarreal, A.M., Butchart, S.H., 2020. Tracking extinction risk trends and patterns in a mega-diverse country: a red list index for birds in Colombia. PLoS one 15, e0227381.

Rhodin, A.G.J., Iverson, J.B., Bour, R., Fritz, U., Georges, A., Shaffer, H.B., van Dijk, P.P., 2021. Turtles of the world: annotated checklist and atlas of taxonomy, synonymy, distribution, and conservation status. In: Rhodin, A.G.J., Iverson, J.B., van Dijk, P.P., Stanford, C.B., Goode, E.V., Buhlmann, K.A., Mittermeier, R.A. (Eds.), Conservation Biology of Freshwater Turtles and Tortoises: A Compilation Project of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group. Chelonian Research Monographs, , 9th ed.8, pp. 1–472.

Roll, U., Feldman, A., Novosolov, M., Allison, A., Bauer, A., Bernard, R., Bohm, M., Chirio, L., Collen, B., Colli, G.R., Dabul, L., Das, I., Doan, T., Grismer, L., Herrera, F. C., Hoogmoed, M., Itescu, Y., Kraus, F., LeBreton, M., Lewin, A., Martins, M., Maza, E., Meirte, D., Nagy, Z., Nogueira, C.C., Pauwels, O.S.G., Pincheira-Donoso, D., Powney, G., Sindaco, R., Tallowin, O., Torres-Carvajal, O., Trape, J.F., Uetz, P., Vidan, E., Wagner, P., Wang, Y.Z., Orme, D., Grenyer, R., Meiri, S., 2017. The global distribution of tetrapods reveals a need for targeted reptile conservation. Nat. Ecol. Evol. 1, 1677–1682. https://doi.org/10.1038/s41559-017-0332-2.

Saha, A., McRae, L., Dodd, C.K., Gadsden, H., Hare, K.M., Lukoschek, V., Bohm, M., 2018. Tracking global population trends: population time-series data and a living planet index for reptiles. J. Herpetol. 52, 259–268.

Schipper, J., Chanson, J.S., Chiozza, F., Cox, N.A., Young, B.E., 2008. The status of the world's land and marine mammals: diversity, threat, and knowledge. Science 322, 225–230.

Sinervo, B., Mendez-de-la-Cruz, F., Miles, D.B., Heulin, B., Bastiaans, E., Villagran-Santa Cruz, M., Lara-Resendiz, R., Martinez-Mendez, N., Calderon-Espinosa, M.L., Meza-Lazaro, R.N., Gadsden, H., Avila, L.J., Morando, M., De la Riva, I.J., Sepulveda, P.V., Rocha, C.F.D., Ibarguengoytia, N., Puntriano, C.A., Massot, M., Lepetz, V., Oksanen, T.A., Chapple, D.G., Bauer, A.M., Branch, W.R., Clobert, J., Sites, J.W., 2010. Erosion of lizard diversity by climate change and altered thermal niches. Science 328, 894–899.

Slavenko, A., Tallowin, O.J.S., Itescu, Y., Raia, P., Meiri, S., 2016. Late quaternary reptile extinctions: size matters, insularity dominates. Glob. Ecol. Biogeogr. 25, 1308–1320.

Stark, G., Tamar, K., Itescu, Y., Feldman, A., Meiri, S., 2018. Cold and isolated ectotherms: drivers of reptilian longevity. Biol. J. Linn. Soc. 125, 730–740.

Stuart, S.N., Chanson, J.S., Cox, N.A., Young, B.E., Rodrigues, A.S., Fischman, D.L., Waller, R.W., 2004. Status and trends of amphibian declines and extinctions worldwide. Science 306, 1783–1786.

Tingley, R., Macdonald, S.L., Mitchell, N.J., Woinarski, J.C.Z., Meiri, S., Bowles, P., Cox, N.A., Shea, G.M., Bohm, M., Chanson, J., Tognelli, M.F., Harris, J., Walke, C., Harrison, N., Victor, S., Woods, C., Amey, A.P., Bamford, M., Catt, G., Clemann, N., Couper, P.J., Cogger, H., Cowan, M., Craig, M.D., Dickman, C.R., Doughty, P., Ellis, R., Fenner, A., Ford, S., Gaikhorst, G., Gillespie, G.R., Greenlees, M.J., Hobson, R., Hoskin, C.J., How, R., Hutchinson, M.N., Lloyd, R., McDonald, P., Melville, J., Michael, D.R., Moritz, C., Oliver, P.M., Peterson, G., Robertson, P., Sanderson, C., Somaweeraa, R., Teale, R., Valentine, L., Vanderduys, E., Venz, M., Wapstra, E., Wilson, S., Chapple, D.G., 2019. Geographic and taxonomic patterns of extinction risk in Australian squamates. Biol. Conserv. 283, 108203. https://doi.org/10.1016/j.biocon.2019.108203.

Tingley, R., Meiri, S., Chapple, D.G., 2016. Addressing knowledge gaps in reptile conservation. Biol. Conserv. 204A, 1–5. https://doi.org/10.1016/j.biocon.2016.07.021.

Tolley, K.A., Tilbury, C.R., Burger, M., 2022. Convergence and vicariance: speciation of chameleons in the cape Fold Mountains, South Africa, and the description of three new species of bradypodion fitzinger, 1843. Afr. J. Herpetol. 71, 14–38.

Trisos, C.H., Merow, C., Pigot, A.L., 2020. The projected timing of abrupt ecological disruption from climate change. Nature 580, 496–501.

Uetz, P., 2022. The reptile database. http://reptile-database.reptarium.cz. (Accessed 30 December 2022).

Venegas, P.J., Garcia-Ayachi, L.A., Chavez-Arribasplata, J.C., García-Bravo, A., 2022. Four new species of polychromatic spiny-tailed iguanian lizards, genus stenocercus (Iguania: Tropiduridae), from Peru. Zootaxa 5115, 1–28.

Wilson, D.E., Reeder, D.M., 2005. Mammal Species of the World (editors), 3rd edition. Johns Hopkins University Press, Baltimore.