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Extinction and extinction vulnerability of amphibians and reptiles in Madagascar

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***Abstract.*—In Madagascar, only two herpetofaunal extinction events are well documented. Both are extinctions of subfossil giant tortoises, which coexisted with humans for more than 1,000 years. Modern extinctions of amphibians and reptiles are also likely, but researchers and conservationists are probably overlooking these extinction events, because the most vulnerable species, with small relict populations, are easily missed during regional surveys. To date, conservation programs in Madagascar have largely ignored many relict distribution species, restricted to transitional or rare habitat types. We provide four examples of species with relict distributions that we consider vulnerable to extinction. Based on ongoing surveys and systematic revisions, many new herpetofaunal species will be described in the future, some of which may require rapid conservation efforts to prevent extinction.**

Conservationists frequently measure extinction vulnerability using the World Conservation Union (IUCN) Red Lists, and fifteen endemic Malagasy amphibians and reptiles are included in the IUCN Threatened List. However, this list appears to reflect a historical bias towards conserving turtles and boas in Madagascar, listing eight species in these groups, although they represent just 2 percent of the island's actual endemic herpetofauna. Ironically, this taxonomic bias may hinder attempts to prevent herpetofaunal extinctions, by promoting some species for conservation activities that are not vulnerable (e.g., tolerant of human habitat modification, or widespread) and ignoring many species that are soon to be lost. For Malagasy amphibians and reptiles, biogeographic data appear to provide more objective criteria with which to assess extinction threats rather than suspected rates of population decline.

Key words. *Extinction, conservation, Madagascar, herpetology, biogeography, reptiles, amphibians*

Introduction

Despite the considerable interest in the amphibian and reptile faunas of Madagascar and the widely held view that the island represents one of the world's top conservation priorities (e.g., Wright 1997), it is surprising that there has been so little discussion regarding the patterns of extinctions (past, present, or future) for these two highly diverse and largely endemic groups. This is of special concern because the objective of most conservation programs in Madagascar is to maintain biodiversity. Therefore these programs should prevent, or at least minimize, future extinctions.

The purpose of this paper is to provide a summary of herpetofaunal extinctions and extinction vulnerability in Madagascar: first by reviewing the evidence of extinction; second by providing examples of species we believe are at imminent threat of extinction; and third by evaluating and summarizing methods used to measure risks of extinctions by the conservation community using the World Conservation Union (IUCN) Red List criteria.

Subfossil extinctions

The only well documented cases of herpetofaunal extinctions in Madagascar are for the two species of giant tortoises, *Dispsochelys grandidieri* and *Dispsochelys abrupta*, which once occupied a large area of the central and western region of the island (Bour 1984). Both species went extinct during Madagascar's "megafauna" extinction event that occurred during the past two thousand years (Dewar 1984). The reasons for their extinctions are unknown, but it is certain that they coexisted with humans on the island between 2000 Before Present (B.P.), the date of earliest human occupation of the island (MacPhee and Burney 1991) and 750 B.P., the youngest carbon date for giant tortoise subfossils in Madagascar (Burleigh and Arnold 1986). Raxworthy and Nussbaum (1996) have suggested that the modern day practice of regular (typically annual) burning of grassland and its peripheral forests, over much of the island, was responsible for destroying the original habitats of grazing animals such as giant tortoises, while MacPhee and Marx (1997) consider their extinction may be due to the human introduction of exotic pathogens that caused hyperdisease.

The former distribution of both species of giant tortoises was vast, and their remains frequently represent the most common subfossil material recovered by paleontological excavations (Dewar 1984). Because of their former large distribution and fact that much of island of Madagascar has still been poorly surveyed, there remains a chance that either species may survive as a small population in one of the remoter regions, although this possibility must now be considered extremely unlikely.

No other extinct reptile or amphibian subfossil material is known from Madagascar, and there are no historically documented cases of species going to extinction.

Possible extinctions

One possible extinction claimed in the literature (IUCN/UNEP/WWF 1987) is the colubrid snake *Liophidium apperti*. This

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Plate 1


Plate 2


Plate 3


Plate 4


Plate 5


Plate 6


Plate 7


Plate 8

Plate captions: **1**. Antanosy day gecko *Phelsuma antanosy*, from a Petriky relict forest fragment that has now been lost. **2**. *Chamaeleo belalandaensis*, at Belalanda. One of Madagascar's rarest chameleons. **3**. Angonoka tortoise *Geochelone yniphora*, photographed at Ampijoroa. **4**. Adult big headed Madagascar side-necked turtle *Erymnochelys madagascariensis*, photographed at the Andranomiditra River, Bevazaha village, Ankarafantsika Reserve. *Photo: Gerardo Garcia Herrero.* **5**. Tomato frog *Dyscophus antongili*, Antongil's Bay. **6**. Dumeril boa *Boa dumerili. Photo courtesy of Kevin and Sue Hanley*. **7**. Madagascar boa *Boa madagascariensis*. *Photo: R. D. Bartlett.* **8**. Sanzinia tree boa *Boa manditra. Photo by Peter Stafford, courtesy of The Natural History Museum, London. Photos 1 and 2: C. J. Raxworthy. Photos 3 and 5 courtesy of Franco Andreone, Museo Regionale di Scienze Naturali, Torino, Italy.*

Plate 9

Plate 10

Plate 11

Plate 12

Plate 13

Plate 14

Plate 15

Plate 16

Plate captions: **9**. Campan's chameleon *Furcifer campani*. **10**. Labord's chameleon *Furcifer labordi* (female), Kirindy. **11**. Minor chameleon *Furcifer minor* (female), photographed at "Mandraka Breeding Centre." **12**. Standing's day gecko *Phelsuma standingi*. **13**. Golden mantella *Mantella aurantiaca*, from Andasibe. *Photo: C. J. Raxworthy.* **14**. *Pyxis planicauda*, photographed at Ampijoroa. **15**. Radiated tortoise *Geochelone radiata*. **16**. Armored chameleon *Brookesia peramata*. *Photos 9 and 12 courtesy of R. D. Bartlett. Photos 10, 11, and 14 courtesy of Franco Andreone, Museo Regionale di Scienze Naturali, Torino, Italy. Photos 15 and 16 courtesy of Kevin and Sue Hanley.*

species was described from a single specimen collected from a forest 7 km north of Befandrina-sud in 1968 (Domergue 1983). Domergue reported that the forest had been subsequently cleared, which prompted IUCN/UNEP/WWF (1987) to consider that "the survival of this snake must now be in question." We think it is premature to consider this species to be extinct, because this region remains so poorly studied, and it appears that similar forest types still survive in nearby sites in the Morombe region. We have collected *Liophidium* c.f. *apperti* at several localities in southern Madagascar, and although these specimens require further taxonomic study, this also suggests this species is not confined to Befandrina-sud.

Possibly the best candidate we have for an extinction event occurring during the past 100 years is for the colubrid snake *Pseudoxyrhopus ankafinaensis*, which was not described until 1994. This very large species is represented by just a single specimen collected in 1880 from montane forest of the High Plateau. Forest of this type is now almost completely degraded in this region (Raxworthy and Nussbaum 1994), and the absence of observations of *P. ankafinaensis* from surviving forest of lower elevation, or other montane forest sites suggests it was endemic to this high elevational region of the High Plateau.

Dubious extinctions

Other species have not been found for more than one hundred years, and, therefore, could also be considered extinct. However, before this conclusion can be made with any certainty, it is important to confirm that the species were collected in Madagascar. During the 1800's, specimen localities were sometimes confused or lost, frequently because museums were receiving collections from throughout the world during this period. An example is the colubrid snake *Pseudoxyrphopus punctatus*, which was thought for a period of more than 50 years to have been collected in Madagascar. Subsequently, this was identified as a Brazilian snake in the genus *Sordellina* (see Raxworthy and Nussbaum 1994).

Another possible example of a species that may not ever have been collected in Madagascar is *Ailuronyx trachygaster*. This giant gecko, known only from a single specimen MNHP 6679 (Muséum National d'Histoire Naturelle, Paris) was collected by an unknown person from a locality listed in the Paris Museum as Madagascar. Interestingly, the two specimens catalogued before *A. trachygaster*: MNHP 6677-8, are both *Ailuronyx seychellensis* collected in the Seychelles (6677 was collected by Péron and Lesueur). Possibly *A. trachygaster* was also collected on the same voyage. *A. trachygaster* is a valid species, with very different characters compared to *A. seychellensis*. Despite some uncertainty about the geographic origin, we suspect *A. trachygaster* is extinct because no new specimens (of what should be a very conspicuous gecko) have been found in more than 140 years.

As a result of recent surveying in Madagascar, most of the rarer species in collections have been rediscovered, such as *Zonosaurus boettgeri*, *Phyllodactylus brevipes*, *Paragehyra petiti*, *Uroplatus alluaudi*, and *Pseudoxyrhopus ambreensis*, but a few notable exceptions remain, especially among the most cryptic groups. For example, among the skinks, the following species have not been collected since their original description: *Mabuya betsileana* (possibly African), *Cryptoscincus minimus*, *Pseudoacontias madagascariensis*, and *Paracontias rothschildi*. Their exact distributions remain unknown at present (in Madagascar or elsewhere) but we consider it premature to consider any of them to be extinct.

Vulnerable to extinction

We consider species in the category "Vulnerable to Extinction" to have populations that are sufficiently small that near-future extinction in the wild can be considered highly likely (without conservation action). These species are restricted to primary habitat that has declined so dramatically, that they now survive only in tiny isolated patches, which are continuing to decline. As a result, the species dependent on this primary habitat are now endemic to a very small region of the island. To illustrate this type of extinction vulnerability, we have selected four species to serve as examples. However, many other herpetofaunal species exhibit similar extinction vulnerability in Madagascar.

Bernard's mantella frog *Mantella bernhardi* (Plate 18A and B). During a survey of Tolongoina made by Nussbaum in 1993, *M. bernhardi* was first discovered, in a single patch of relict forest. Within months, commercial collectors visited the locality and supplied André Peyrieras, a commercial exporter, with animals to be sold into the pet trade. Vences et al. (1994) described this species based on animals they obtained from commercial collectors working for Peyrieras. They provided no data on the exact locality, habitat requirements, or conservation concerns of this species, because they never saw this species in the wild.

A subsequent visit to the Tolongoina region by Raxworthy in 1994 discovered that the only known *M. bernhardi* habitat had been further cleared, so that no more than 20 ha of forest survived (Plate 17). No other populations were discovered during this visit, and almost all other primary rain forest had been cleared from the area. Deforestation of primary forest has been so extensive in this region that almost no fragments now survive east of the Faraony River. Topographic maps indicate that this forest was almost entire during aerial photography made of the region between 1950 and 1965 (FTM 1974).

Although it is likely that *M. bernhardi* once had a more widespread distribution, the deforestation pattern of low elevation rain forest (below 800 m elevation) in this region suggests that little forest of this type now survives. The closest protected forest of this type occurs in the lowest elevational areas of the Ranomafana National Park (the southern boundary limit is 18 km to the northwest). It is not known if this species occurs there, or even if the habitat is similar to that at Tolongoina. The low elevation rain forest at Manombo Reserve (140 km to the south) does not appear to have populations of *M. bernhardi* based on a survey by Raxworthy in 1991.

Because no known populations of *M. bernhardi* occur within a protected area and its habitat appears to have been almost completely destroyed, we consider this species extremely vulnerable to extinction.

Antanosy day gecko *Phelsuma antanosy* (Plate 1). This day gecko is restricted to coastal fragments of forest in the Tolagnaro region of southeastern Madagascar. Raxworthy and Nussbaum (1993) described three sites (forest fragments) in the description of this species at Petriky, Ste. Luce, and Tapera. Since then, one new site has been discovered near Manambaro, and one site (the Petriky fragment, area 81 ha in 1989) has been completely destroyed. None of the three surviving forest fragments is greater than 191 ha, and the Manambaro site is decreasing in area rapidly as a result of annual burning.

Unlike some *Phelsuma* species, *P. antanosy* does not survive in degraded or heavily modified habitats and appears to be entirely dependent on the transitional dry-humid forests that are restricted to a small region of the southeast. This habitat has now been almost completely lost from the region, having been degraded and cleared for charcoal production and agricultural land. None of the forest fragments where *P. antanosy* occurs is within a protected area.

The surviving populations are now so small that we consider this species to be extremely vulnerable to extinction. Conservation efforts are required if the last fragments of habitat are to be saved.

Belalanda chameleon *Chamaeleo belalandaensis* (Plate 2). Very little information exists on either the distribution or habitat requirements of this chameleon. However, all data to date suggest it is endemic to a tiny region of Madagascar. The only locality is Belalanda, Southwestern Madagascar, where Raxworthy has recorded individuals as recently as 1995. However, we were unable to find this species at other sites, despite intensive herpetofaunal surveys within 10-50 km of Belalanda. The habitat where this chameleon was recorded is degraded gallery forest, which has now been almost completely cleared. Because *C. belalandaensis* was not found in the other surviving primary forest habitats of the region, we suspect it is restricted to gallery forest.

This chameleon is an example of a species for which biogeographic data are urgently needed. It would be valuable to record the exact distribution limits for this chameleon, so that conservation efforts could be directed at those populations, which appear to be most viable. The species has already been subject to some commercial collecting, but the impact on the population is not known. The very localized distribution of *C. belalandaensis*, in part confirmed by our survey efforts in surrounding areas, suggests that this species is vulnerable to extinction because of the apparently tiny surviving populations.

Angonoka tortoise *Geochelone yniphora* (Plate 3). This tortoise is restricted to an area of less than 1,000 km^2 in the Baly Bay area of Western Madagascar. The distribution appears to be relict, because the species is now confined to two isolated areas, one to the east of the Baly Bay (Cap Sada), and the other to the west (Belambo). Dispersal across the bay is likely to be very limited or impossible. Therefore, the eastern and western populations appear to be genetically isolated. Only five sites are known or suspected to have *G. yniphora* populations (Durrell et al. 1994). The suspected sites are based on interviews with local people and the occurrence of suitable habitat. The wild populations are thought to have declined recently due to habitat loss, predation of eggs, and juveniles by African bush pig (*Potamochoerus larvatus*), and collecting by people (Durrell et al. 1994). At Cap Sada the first detailed population study is now underway.

The isolated eastern and western populations of *G. yniphora* suggest this species was previously distributed to the south of Baly Bay and that the distribution range has contracted since this time. The habitat of this tortoise is a mosaic of deciduous forest and bamboo scrub, which appears to be replaced by a palm savanna as a result of frequent burning. Between 1949-1973, Curl et al. (1985) reported only minor change in tortoise habitat distribution, and suggested this habitat is no longer declining. However, it should be noted that during this same period, the setting of fires was both illegal and frequently enforced by local communities.

The tiny isolated populations and the restricted area of surviving habitat clearly indicate that *G. yniphora* is vulnerable to extinction if further habitat decline continues. A major conservation program (Project Angonoka) coordinated by the Malagasy Water and Forests Authority and Jersey Wildlife Preservation Trust is now underway in the Cap Sada region to protect this population.

IUCN Threatened species

This section includes those species listed with a threatened category (Critically Endangered, Endangered, or Vulnerable) in the most recent IUCN Red List (IUCN 1996). Threatened species, as recognized by IUCN, refers specifically to the level of risk of extinction. Fifteen endemic Malagasy amphibians and reptiles are currently listed as threatened in the Red List; three species are classified as Endangered, and another 12 as Vulnerable. A significant advance with the new IUCN categories is that threats are presented in a quantified format. A summary of these endemic species, as well as their perceived risks of extinction, is given in Table 1.

IUCN Endangered species

Big headed Madagascar side-necked turtle *Erymnochelys madagascariensis* (Plate 4). The criteria used for considering this turtle as endangered is based on a 50 percent population decline in 10 years or three generations. The generation time (average age of parents in the population, as used by IUCN) for this turtle is unknown, but without doubt will be greater than 10 years. For long-lived species IUCN suggests a cap of 75 years (IUCN 1996). Even working with this time span, however, the problem is a lack of population data for this species, both modern and historical.

There is no doubt that populations are being exploited by fishing practices, and Kuchling and Mittermeier (1993) have presented evidence that two populations have gone extinct out of a sample of nine lakes. Nevertheless, these authors recognized that the status of river populations have not been estimated because of an almost complete lack of surveys within the rivers of Western Madagascar. In addition, we still lack modern data on either lake or river populations throughout much of the species' distribution range, especially the many remote regions of the west.

Because our knowledge of the populations of *E. madagascariensis* is so incomplete, it is questionable if we can claim even a suspected population reduction of 50 percent. The large historical distribution area of this turtle, with an extent of occurrence of approximately 100,000 km^2, does not suggest to us that this species is yet at high risk to extinction, although clearly more field work is required to determine the current distribution of this species.

Angonoka tortoise *Geochelone yniphora*. Like *E. madagascariensis*, the three-generation time for *G. yniphora* will be greater than 10 years. We are unaware of data to support a 50 percent population decline over either 10 years or three generations. However, this tortoise does qualify for Endangered status based

Plate 17. Some of the last known surviving *Mantella bernhardi* forest habitat cleared for cultivation between 1993-4. *Photo: C. J. Raxworthy.*

Plate 18A. Bernard's mantella frog *Mantella bernhardi*. Probably the rarest Mantella species. *Photo courtesy of Franco Andreone, Museo Regionale di Scienze Naturali, Torino, Italy.*

Plate 18B. *Mantella bernhardi* (belly pattern). *Photo courtesy of Franco Andreone, Museo Regionale di Scienze Naturali, Torino, Italy.*

on the criteria of an extent of occurrence less than 5,000 km^2, and less than 5 isolated populations (see earlier).

Madagascar flat tailed tortoise *Pyxis planicauda* (Plate 14). Adult wild *P. planicauda* are reported to have 10-30 growth rings (Kuchling and Bloxam 1988), which appear to reflect the growth between each period of annual aestivation[d]. Using a mean generation time of 20 years, three generations would represent 60 years. The Endangered category given to this tortoise is based on a 50 percent decline in the population during this period.

Without question, populations of this tortoise are declining due to habitat destruction for cultivation (Kuchling and Bloxam 1988; Bloxam et al. 1993; Raxworthy, pers. obs.). However, our knowledge of the species distribution is actually improving. New localities are being discovered, including important range extensions further to the north (Behler et al. 1993; Bloxam et al. 1993). The extent of occurrence for *P. planicauda* is currently about 500 km^2 (based on the localities given in Fig. 1, Behler et al. 1993), with the species endemic to a small region of coastal, western, deciduous forest between the Morondava and Tsiribihina Rivers. This justifies *P. planicauda* being considered Endangered (the extent of occurrence is significantly less than 5,000 km^2) based on its small distribution, rather than the criteria of rate of population decline. The localized distribution of this species, and its dependence on native forest, suggests this species is vulnerable to extinction.

IUCN Vulnerable species

Of the 12 species classified as Vulnerable, 11 are so classification based on a criteria of a 20 percent reduction in population over 10 years or three generations. The mean wild generation time is unknown for any of these species, although a study of radiated tortoise *Geochelone radiata* at one site has yielded some data on the population age structure (Razafindrakoto 1987). The population size and rate of decline have never been measured for these species, although populations of some species restricted to primary habitats are declining in areas subjected to habitat loss. For those species restricted to primary habitats, it may be reasonable to positively correlate rates of habitat loss (e.g., based on satellite images) to rates of population decline.

Four of the Vulnerable species: the tomato frog *Dyscophus antongili* (Plate 5), the Dumeril boa *Boa dumerili* (Plate 6), the Madagascar boa *Boa madagascariensis* (Plate 7), and the Sanzinia tree boa *Boa manditra* (Plate 8), are not restricted to primary vegetation. *D. antongili* is found in secondary habitats, such as around villages and in areas of cultivation (Raxworthy 1991), and even in towns such as Maroantsetra (Glaw and Vences 1994). All three of the Malagasy *boas* (*B. dumerili*, *B. madagascariensis*, and *B. manditra*) are frequently found in heavily degraded habitats and cultivated areas, even including close proximity to villages where they are probably feeding on commensal rats. For these species, the loss of primary forest does not lead to local extinction, although their population changes (negative or positive), when primary forest is converted, are not known.

The most likely source of population decline for *D. antongili*, and the three species of boa, is commercial collecting, although now all four species are listed on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix I, which prevents legal international trade. Malagasy boas are collected in regions such as Marovoay to supply a domestic leather trade. However, boas continue to be among the most common snakes found in Madagascar, and the scale of commercial collecting may be comparable to the number of road kills that can be seen throughout Madagascar during the rainy season. The approximate extent of occurrence of each species is: *D. antongili* 10,000 km^2, *B. dumerili*, 120,000 km^2, *B. madagascariensis* 40,000 km^2, and *B. manditra*, 100,000 km^2. Based on the large distribution area, and the broad tolerance to habitat degradation, none of these species appear at risk to extinction.

Of the other eight vulnerable species which are restricted to primary habitats, it is impossible for us to assess the criteria used for the following species: Campan's chameleon *Furcifer campani* (Plate 9), Labord's chameleon *Furcifer labordi* (Plate 10), the Minor chameleon *Furcifer minor* (Plate 11), Standing's day gecko *Phelsuma standingi* (Plate 12), and the golden mantella *Mantella aurantiaca* (Plate 13), because these are based on rates of population decline (observed or suspected) for which we have been unable to find obvious supporting data.

Table 1. IUCN threatened species of endemic amphibians and reptiles of Madagascar (IUCN 1996).

SPECIES	CATEGORY	SUMMARY OF CRITERIA
Erymnochelys madagascariensis	ENDANGERED	50% population decline in 10 years or 3 generations
Pyxis planicauda	ENDANGERED	50% population decline in 10 years or 3 generations
Geochelone yniphora	ENDANGERED	50% population decline in 10 years or 3 generations, < 5,000 km^2 extent of occurance and < 5 isolated populations
Dyscophus antongili	VULNERABLE	20% population decline in 10 years or 3 generations
Mantella aurantiaca	VULNERABLE	20% population decline in 10 years or 3 generations
Pyxis arachnoides	VULNERABLE	< 20,000 km^2 extent of occurance, < 10 isolated populations and decline in population
Geochelone radiata	VULNERABLE	20% population decline in 10 years or 3 generations < 20,000 km^2 extent of occurance, < 10 isolated populations
Phlesuma standingi	VULNERABLE	20% population decline in 10 years or 3 generations
Brookesia peramata	VULNERABLE	20% population decline in 10 years or 3 generations and < 100 km^2 area of occupancy or < 5 locations
Furcifer campani	VULNERABLE	20% population decline in 10 years or 3 generations
Furcifer labordi	VULNERABLE	20% population decline in 10 years or 3 generations
Furcifer minor	VULNERABLE	20% population decline in 10 years or 3 generations

These species have been commercially traded, but the impact of this trade on wild populations is unknown or only poorly known.

Two of these species have a very limited distribution: *M. aurantiaca* is restricted to eastern rain forest with an approximate extent of occurrence of 3,000 km^2 and *P. standingi* restricted to deciduous western forest in the Toliara region with an approximate extent of occurrence of 2,500 km^2 (although an unconfirmed report suggests this species may also occur further north).

In the case of *P. standingi* we have found this gecko is extremely rare (if not locally extinct) in forest within 5 km of major roads at Ifaty (none were seen during at least 60 man-days of searching). Commercial collecting has been occurring in this area for some time, and in many cases collecting poles could still can be found lying against baobab tree trunks, left by the local collectors in the hope of catching any remaining geckos. However, because the original population size and density in this region is unknown, the impact of commercial collecting cannot be measured.

The impact of collecting on *M. aurantiaca* is also unknown. Zimmermann and Zimmermann (1994) suggest that local population extinctions occurred in a swamp system between 1966 and 1993 as a result of habitat loss. They therefore propose that commercial collecting be prevented by placing *M. aurantiaca* on Appendix I of CITES.

For *M. aurantiaca* and *P. standingi*, their limited known distributions, primary habitat requirements, and commercial collecting pressures, all suggest that both species may be vulnerable to extinction.

Distribution data is used as criteria for Vulnerable status for three species: *Pyxis arachnoides*, *G. radiata* (Plate 15), and *Brookesia perarmata* (Plate 16). For the two tortoise species, *P. arachnoides* and *G. radiata*, the extent of occurrence is actually greater than 20,000 km^2 (we estimate both around 30,000 km^2), one of the criteria used to support the vulnerable status. In addition, although the populations of these species are also likely to becoming more fragmented, as a result of habitat loss, there are without doubt many more than 10 isolated populations (another criteria used to assign these species vulnerable status, see Table 1). Therefore, the only justification that can be made for considering these tortoises, as Vulnerable, using the IUCN criteria, is the rate of observed or suspected population decline, for which we currently have very little quantitative information. The large distributions of *P. arachnoides* and *G. radiata* do not suggest that either species is yet threatened by extinction.

B. perarmata is only known from one site: Bemaraha, in Western Madagascar. Although the surface area of the Bemaraha Reserve is large (152,000 ha), our survey of this protected area at three well separated sites, yielded this chameleon at just one locality indicating it is not continuously distributed throughout the reserve. This clearly supports the "less than five site" criteria for Vulnerable status.

Discussion

Despite the major environmental problems that have been developing for so long in Madagascar, it is perhaps surprising that we have no evidence of any herpetofaunal extinction events occurring on the island over the past 500 years. Although this suggests the island's species diversity has not declined during this period, we believe herpetofaunal extinctions have been occurring, and are occurring now, but that researchers and conservationists have overlooked these events.

Species most vulnerable to extinction will have small populations, and therefore tiny relict distributions. This makes them difficult to survey, and, therefore, easily missed. A modern example of this is *P. antanosy*, distributed in a region of Madagascar that has been subject to herpetological collecting for over 100 years. We suspect many more herpetofaunal species are on the verge of going extinct in transitional or rare habitat types. Regions that experience highly localized climatic conditions frequently have unusual transitional habitats in Madagascar. In many cases these localized habitats have been further reduced to small relict patches as a result of human exploitation and have attracted little research attention because of their small size or isolated locality. Examples of major sites we have surveyed, which offer these conditions, include Analavelona, Isalo, Bemaraha, Kelifely, Ambohijanahary, Namoroka, and Ankarana. We are in the process of describing new species from all of these sites, most of which are likely to be locally endemic, but active conservation programs are now underway in just three sites (Isalo, Bemaraha, and Ankarana). Many of these new species are reduced to such small population sizes that they are obviously some of the most vulnerable herpetofaunal species in Madagascar. Other potentially vulnerable species include *Phelsuma masohoala*, *Uroplatus malahelo*, *Pseudoxyrhopus kely*, and *Alluaudina mocquardi*.

Of the 15 endemic Malagasy amphibians and reptiles considered Threatened by the IUCN Red List, we consider (based on distribution and habitat requirements) just three species to be obviously vulnerable to extinction: *P. planicauda*, *G. yniphora*, and *B. perarmata*. Another two species, *M. aurantiaca* and *P. standingi*, appear to also have small distributions, but further fieldwork is required to confirm this. The other 10 species do not appear to be vulnerable to extinction because of their much larger distributions, and in some cases, broad tolerance to human modification of primary habitats.

In part, the IUCN Threatened List actually reflects a historical bias towards conserving turtles and boas in Madagascar, rather than actual risks to extinction. It is worth noting that 8 of the 15 Red List species are boas or turtles (53 percent), although this group represents just 2 percent of the island's actual endemic herpetofauna. Ironically, this conservation bias is actually hindering attempts to prevent herpetofaunal extinctions in Madagascar, by promoting some species for conservation activities that are not vulnerable and by ignoring many species that are about to be lost.

Rates of past, present, or future population decline (observed, estimated, inferred, or suspected) are used as IUCN criteria for all but one of the 15 threatened species. This surprises us, as we are unsure what types of evidence were used to support or estimate these rates of population decline. For the herpetofauna of Madagascar, we think that it would be far more effective to base vulnerability to extinction on biogeographic data, rather than estimated population declines. The advantage is that biogeographic data is available for most species, and these data can be compared between different taxa to determine conservation priorities. Of course, biogeographic data are never complete for any species, but it can be obtained with far less effort than undertaking population studies throughout a species distribution range.

Table 2 includes four biogeographic criteria that we consider to be the most important in determining vulnerability to extinction for amphibians and reptiles in Madagascar. Other population factors will also influence the risk of extinction (e.g., population density, generation time, reproductive output, predation, and human collecting), but since it is unlikely we will ever have detailed information of this type over the entire distributional range on any herpetofaunal species, we think the most objective data set available to us is biogeographic.

Table 2. Measuring extinction vulnerability with biogeographic criteria.

BIOGEOGRAPHIC CRITERIA	EXTINCTION RISK	
	HIGH	LOW
EXTENT OF OCCURANCE	Small	Large
NUMBER OF KNOWN SITES	Few	Many
DISTRIBUTION STRUCTURE	Fragmented	Continuous
HABITS	Specialist of a declining habitat	Specialist of a stable habitat

Provided that taxonomic biases are avoided, we believe that the analysis of biogeographic data has the potential to reveal a much more realistic picture of extinction threats to the amphibians and reptiles in Madagascar, compared to the criteria currently being employed. This will identify those species of greatest concern, which could then become the focus of conservation programs aimed at maintaining existing levels of biodiversity in Madagascar.

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