DER ZOOLOGISCHE GARTEN

THE ZOOLOGICAL GARDEN

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THE ZOOLOGICAL GARDEN covers all aspects of zoological gardens, as for example

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- conservation of rare and threatened species
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- veterinary medicine
- zoological pedagogic
- history of zoological gardens
- news from zoological gardens
- book reviews

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Review of Malagasy amphibians and reptiles kept and bred in the Zoological and Botanical Garden of the town of Plzen (Czech Republic)

Übersicht über die madagassischen Amphibien und Reptilien, die im Zoologischen und Botanischen Garten der Stadt Pilsen (Tschechische Republik) gehalten und gezüchtet werden

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Abstract

The Zoological and Botanical Garden of the town of Plzen specialises in flora and fauna with island distribution. The history of keeping and breeding amphibians and reptiles from Madagascar and Indian Ocean islands is presented together with notes on biology of some species. Between the years 1998 and 2021 the Zoological and Botanical Garden of the Town of Plzen kept 143 taxa of reptiles and 43 species of amphibians from this region. In the mentioned period 60 reptile taxa and 9 amphibian species successfully reproduced. We also present some interesting data on longevity of individual animals.

Keywords: Madagascar, Indian Ocean islands, captive breeding, reptiles, amphibians, conservation

Introduction

Indian Ocean islands have a very high degree of endemism of both reptiles and amphibians. The largest and most diverse island, Madagascar, has 368 endemic amphibians out of 371 species occurring on the island (AmphibiaWeb, 2021). A total of 444 species of reptiles was

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recorded, of which more than 95% are endemic (Uetz et al., 2021). A similarly high degree of endemism is recorded on most of the much smaller islands, e.g. the Seychelles have 13 endemic amphibians out of 14 species or the Comoros with Mayotte have 3 endemics out of 4 native species (AmphibiaWeb, 2021). Unfortunately, a lot of species, especially on Mascarene islands, either went extinct in recent centuries or were found as subfossils and have not been described yet (Cheke & Hume, 2010). As for Malagasy reptiles, about 40% of native species are currently threatened with extinction (Jenkins et al., 2014). The situation of amphibians is even worse. From 314 assessed Malagasy amphibian species, 21 are recognised as critically endangered, 80 as endangered and 44 as vulnerable. On the much smaller Seychelles islands, 50% of the amphibian species and 40% of the reptiles are threatened with extinction (IUCN, 2021).

Today, when the crisis of species extinction has reached such daunting dimensions, captive breeding and other *ex-situ* conservation tools should be the last resort for preserving biodiversity (Rahbek, 1993). The Conservation Strategy for the Amphibians of Madagascar has proposed captive breeding as a potential tool to address amphibian declines. However, this potential can only be realised if sufficient skill and experience exists within captive breeding establishments to be able to respond to the upcoming challenges. The breeding success across all Malagasy amphibians is quite limited. The exchange of knowledge is crucial for increasing the chances of successful captive breeding programmes and a lot can be gained by the collaboration of zoos and private breeders (García et al., 2008). There has been slightly more success in breeding at least some taxonomic groups of reptiles, especially by private breeders.

Zoological and Botanical Garden of the town of Pilsen specializes in flora and fauna with island distribution. In 1993, the garden started keeping Malagasy reptile species in the newly opened succulent house. We started to specialize in island species after 2001, when a new breeding complex was built in the former carnivores house. In the same year, the AKVA TERA exhibit was opened after reconstruction in the centre of the city of Pilsen. Several amphibian species from this region were kept and bred there as well. In 2007, the Malagasy Pavilion was opened to the public with several taxa of reptiles on exhibit. The succulent house was reconstructed in 2020. It is newly called the World of Drought and animals and plants are grouped here thematically. The exhibit of dry NW Madagascar forests contains several reptile taxa, too. Until now, the only time when amphibians from the Malagasy region were shown to the public was when the exhibit Island Treasures in the Rhino Pavilion opened in 2017. The exhibit is still open today, having undergone only minor changes. Recently, one part has been dedicated to forests of Eastern Madagascar and another one to Frégate Island. As you can see further, most of the amphibian and reptile species were only kept in the breeding facilities both in the Zoo and AKVA TERA. There are three rooms with different climatic conditions in the zoo, two are warmer, while the colder one has a night drop of temperature to 17°C (Fig. 1). Two rooms were reconstructed and refurbished with new terraria in 2019. Research conducted by the first author on the genus *Phelsuma* began in the same year.

Material and methods

The review is based on the data from the Zoological Information Management Software (ZIM) and personal records of both authors. The nomenclature and systematics follow The Reptile Database (Uetz et al., 2021) and AmphibiaWeb (2021). Conservation status of all taxa was taken over from the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (IUCN, 2021).

Fig. 1: There are three rooms with different climatic conditions in the zoo. Photo: Tomáš Peš jr

Results

Overview of all taxa kept in the period from 1 Jan 1998 to 1 Nov 2021 is shown in Table 1. The years with successful breeding and IUCN categories are shown as well.

Tab. 1: List of reptiles and amphibians from Indian Ocean islands kept and bred in the Zoological and Botanical Garden of the town of Plzen and their conservation status based on the IUCN Red List of Threatened Species (IUCN, 2021) (CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient; NE = Not Evaluated).

Taxon (IUCN Red List Category)	Years of keeping the taxon	Breeding the taxon in the years
Reptilia		
Testudines		
Testudinidae		
Astrochelys radiata (CR)	2000–2021	2011–2016, 2018–2019
Pyxis arachnoides arachnoides (CR)	2001–2021	2005, 2006, 2013, 2020, 2021
Pyxis planicauda (CR)	2001–2007	
Pelomedusidae		
Pelomedusa subrufa (NE)	1998–2021	2002, 2005, 2018
Pelusios castanoides (LC)	2007–2021	
Pelusios subniger (LC)	2006–2021	
Squamata		
Chamaeleonidae		
Brookesia ebenaui (VU)	2016–2017	
Brookesia stumpffi (LC)	2016–2017	
Brookesia thieli (LC)	2004, 2016–2017	
Calumma crypticum (LC)	2016–2017	
Calumma malthe (LC)	2016–2017	
Calumma parsonii (NT)	2016–2017	
Furcifer antimena (VU)	2016	
Furcifer bifidus (LC)	2016–2017	
Furcifer lateralis (LC)	2008	
Furcifer major (LC)	2016–2017	
Furcifer minor (EN)	2016–2017	
Furcifer oustaleti (LC)	2004–2020	2009
Furcifer pardalis (LC)	2008–2013, 2019–2021	2009
Furcifer rhinoceratus (VU)	2008	
Furcifer verrucosus (LC)	2006–2015	2009
Furcifer wilsii (LC)	2016–2017	
Iguanidae		
Chalarodon madagascariensis (LC)	2002–2004, 2006–2011, 2016–2021	2021
Oplurus cuvieri (LC)	2000–2021	
Oplurus cyclurus (LC)	1998–1999, 2002–2021	
Oplurus fierinensis (LC)	2005–2014, 2016–2021	
Oplurus grandidieri (LC)	2006–2021	

Tab. 1: Continued.

Taxon (IUCN Red List Category)	Years of keeping the taxon	Breeding the taxon in the years
Oplurus quadrimaculatus (LC)	2006–2021	
Oplurus saxicola (LC)	2009–2012	
Gekkonidae		
Blaesodactylus antongilensis (LC)	2006–2021	2010, 2013, 2017, 2019–2021
Blaesodactylus boivini (VU)	2006–2021	
Blaesodactylus sakalava (LC)	2002–2021	2005–2007, 2009, 2011–2012, 2014, 2021
Ebenavia inunguis (LC)	2009–2011, 2018–2020	2009, 2019
Geckolepis cf. *petiti*	2008–2013	
Geckolepis cf. *polylepis*	2008–2011	
Geckolepis maculata (LC)	2006–2018	
Geckolepis typica (LC)	2006–2009	
Hemidactylus mercatorius (LC)	2009–2021	2009
Hemidactylus platycephalus (LC)	2011–2021	2012–2014, 2016–2021
Lygodactylus arnoulti (LC)	2007–2013	2008
Lygodactylus guibei (NT)	2018–2021	
Lygodactylus cf. *madagascariensis* (VU)	2010–2016	2010–2012, 2014
Lygodactylus miops (LC)	2011	
Lygodactylus pictus (LC)	2018–2021	2021
Matoatoa brevipes (VU)	2018	
Paroedura androyensis (VU)	2002–2009	
Paroedura bastardi (LC)	2006–2018	
Paroedura gracilis (LC)	2006–2011	
Paroedura guibei (LC)	2002–2005, 2018–2019, 2021	2002
Paroedura ibityensis (NT)	2005–2017, 2019–2021	2006, 2009, 2020–2021
Paroedura masobe (EN)	2006	
Paroedura oviceps (NT)	2018–2021	
Paroedura picta (LC)	2002–2014	2002–2004, 2009–2010, 2012–2013
Paroedura stumpffi (LC)	2010–2021	2012–2017, 2019–2020
Paroedura vazimba (VU)	2009–2016, 2021	2010
Phelsuma andamanense (LC)	2009–2014, 2016–2021	2019–2021
Phelsuma astriata semicarinata (LC)	2020–2021	2021
Phelsuma barbouri (LC)	2010–2011	
Phelsuma borbonica borbonica (EN)	2011–2018	
Phelsuma breviceps (VU)	2008–2009, 2020–2021	
Phelsuma cepediana (LC)	2010–2017, 2019–2020	
Phelsuma dubia (LC)	2004–2008	
Phelsuma flavigularis (EN)	2015–2021	
Phelsuma grandis (LC)	1998–2021	2001–2021
Phelsuma guttata (LC)	2009–2020	2013–2016
Phelsuma hielscheri (VU)	2010–2021	2019
Phelsuma hoeschi (DD)	2020–2021	

Tab. 1: Continued.

Taxon (IUCN Red List Category)	Years of keeping the taxon	Breeding the taxon in the years
Phelsuma inexpectata (CR)	2010–2021	2010–2012, 2014, 2017
Phelsuma klemmeri (EN)	2006–2021	2020–2021
Phelsuma laticauda angularis (LC)	2021	
Phelsuma laticauda laticauda (LC)	2002–2021	2004, 2010–2017, 2019–2021
Phelsuma lineata bombetokensis (LC)	2021	
Phelsuma lineata elanthana (LC)	2006–2013	
Phelsuma lineata lineata (LC)	2004–2012, 2014–2021	2004, 2011, 2020–2021
Phelsuma madagascariensis boehmei (LC)	2008–2018	2011, 2014
Phelsuma madagascariensis kochi (LC)	2004–2021	2009–2021
Phelsuma madagascariensis madagascariensis (LC)	2004–2020	2008–2018
Phelsuma m. madagascariensis from St. Marie Is. (LC)	2021	
Phelsuma modesta modesta (LC)	2010–2017	
Phelsuma modesta leiogaster (LC)	2008–2017	
Phelsuma mutabilis (LC)	2020–2021	2021
Phelsuma nigristriata (VU)	2006–2021	2011–2014, 2019–2021
Phelsuma ornata (LC)	2006–2013, 2019–2021	2019
Phelsuma parkeri (LC)	2019–2021	2021
Phelsuma pasteuri (NT)	2007–2011, 2019–2021	
Phelsuma quadriocellata quadriocellata (LC)	2004–2017, 2019–2021	2005, 2007–2009, 2011
Phelsuma robertmertensi (EN)	2006–2021	2021
Phelsuma seippi (EN)	2006–2021	2014–2015, 2020–2021
Phelsuma serraticauda (EN)	2010–2015	
Phelsuma standingi (VU)	1998–2021	2005–2021
Phelsuma sundbergi ladiguensis (LC)	2017–2021	
Phelsuma sundbergi longinsulae (LC)	2018–2021	2019, 2021
Phelsuma vanheygeni (EN)	2016–2017	
Phelsuma v-nigra comoraegrandensis (LC)	2007–2018	2007–2008, 2011
Phelsuma v-nigra v-nigra (LC)	2006–2007	
Uroplatus alluaudi (NT)	2021	
Uroplatus ebenaui (VU)	2004–2008	
Uroplatus fimbriatus (LC)	2002–2003, 2005–2008	
Uroplatus guentheri (EN)	2009–2010	
Uroplatus henkeli (VU)	2001–2021	2006, 2009
Uroplatus lineatus (LC)	2002–2021	2005, 2020
Uroplatus phantasticus (LC)	2004–2006	
Uroplatus sameiti (LC)	2003–2009	2006
Uroplatus sikorae (LC)	2002–2004, 2006–2009	
Gerrhosauridae		
Tracheloptychus madagascariensis (LC)	2009–2021	
Tracheloptychus petersi (VU)	2006–2021	2021
Zonosaurus haraldmeieri (NT)	2008–2021	

Tab. 1: Continued.

Taxon (IUCN Red List Category)	Years of keeping the taxon	Breeding the taxon in the years
Zonosaurus karsteni (LC)	2006–2021	2020
Zonosaurus laticaudatus (LC)	1998–2021	2009, 2018–2020
Zonosaurus madagascariensis (LC)	2006–2021	2011, 2019–2021
Zonosaurus maximus (VU)	2006–2014, 2018–2021	
Zonosaurus ornatus (LC)	2005–2021	
Zonosaurus quadrilineatus (VU)	1998–2021	
Zonosaurus trilineatus (LC)	2010–2021	
Scincidae		
Amphiglossus astrolabi (LC)	2020–2021	
Amphiglossus reticulatus (LC)	2020–2021	2021
Brachyseps macrocercus (LC)	2011–2021	2021
Grandidierina fierinensis (LC)	2020–2021	
Madascincus cf. *melanopleura* (LC)	2006–2018	
Madascincus igneocaudatus (LC)	2016–2017	
Madascincus sp.	2006–2009	
Pygomeles braconnieri (LC)	2020	
Trachylepis aureopunctata (LC)	2009	
Trachylepis elegans (LC)	2007, 2009, 2019–2021	2021
Trachylepis gravenhorstii (LC)	2007–2011	
Trachylepis madagascariensis (LC)	2008–2009	
Boidae		
Acrantophis dumerili (LC)	1998–2021	2004, 2017, 2019
Acrantophis madagascariensis (LC)	2005–2021	2012
Sanzinia madagascariensis madagascariensis (LC)	1998–2021	2004
Sanzinia madagascariensis volontany (LC)	2006–2021	
Lamprophiidae		
Dromicodryas bernieri (LC)	2006–2008	
Dromicodryas quadrilineatus (LC)	2005	
Langaha madagascariensis (LC)	2006, 2014–2015	
Leioheterodon geayi (LC)	2006–2021	2020
Leioheterodon madagascariensis (LC)	1998–2021	1999–2001, 2004–2005, 2010–2013, 2015–2017, 2019–2020
Leioheterodon modestus (LC)	1998–2021	2018
Madagascarophis colubrinus occidentalis (LC)	2006–2021	2016, 2020–2021
Madagascarophis colubrinus pastoriensis (LC)	2006–2021	
Madagascarophis cf.*meridionalis* (LC)	2007–2021	2020–2021
Parastenophis betsileanus (LC)	2008–2009	
Pseudoxyrhopus quinquelineatus (LC)	2006–2021	
Pseudoxyrhopus tritaeniatus (LC)	2014–2015	
Thamnosophis lateralis (LC)	2005	

Tab. 1: Continued.

Taxon (IUCN Red List Category)	Years of keeping the taxon	Breeding the taxon in the years
Amphibia		
Anura		
Hyperoliidae		
Heterixalus alboguttatus (LC)	2006–2021	2009, 2011–2021
Heterixalus betsileo (LC)	2004, 2006–2012, 2014–2021	
Heterixalus madagascariensis (LC)	2006–2020	2012–2013
Heterixalus rutenbergi (LC)	2006	
Mantellidae		
Boophis albilabris (LC)	2006–2014	
Boophis albipunctatus (LC)	2010	
Boophis boehmei (EN)	2007	
Boophis elenae (NT)	2006–2007, 2014–2015	
Boophis goudotii (LC)	2006, 2010	
Boophis idae (LC)	2004–2006	
Boophis luteus (LC)	2006–2007, 2010–2019	
Boophis madagascariensis (LC)	2006–2007, 2010	
Boophis microtympanum (LC)	2007–2009	
Boophis pyrrhus (LC)	2014–2015	
Boophis rappiodes (LC)	2006–2008, 2011–2012	
Boophis septentrionalis (LC)	2010	
Boophis sibilans (LC)	2007	
Guibemantis bicalcaratus (LC)	2006–2010	
Guibemantis flavobrunneus (LC)	2007–2008	
Guibemantis liber (LC)	2011–2021	
Guibemantis pulcher (LC)	2006–2009, 2011–2017	
Mantella aurantiaca (EN)	2001–2013, 2017–2021	2002, 2021
Mantella betsileo (LC)	2008–2021	2010
Mantella expectata (EN)	2019–2021	2020–2021
Mantella laevigata (LC)	2021	
Mantella madagascariensis (VU)	2002–2013	
Mantella pulchra (NT)	2002–2017	2010
Mantella viridis (EN)	2009–2021	2020–2021
Mantidactylus betsileanus (LC)	2019–2020	
Mantidactylus femoralis (LC)	2006–2008	
Mantidactylus lugubris (LC)	2006	
Microhylidae		
Cophyla grandis (LC)	2006–2011	
Dyscophus antongilii (LC)	2003–2005	
Dyscophus guineti (LC)	2002–2021	2012–2013, 2016, 2021
Dyscophus insularis (LC)	2004–2005	
Plethodontohyla tuberata (NT)	2004–2008	
Scaphiophryne boribory (VU)	2007–2008, 2011	

Tab. 1: Continued.

Taxon (IUCN Red List Category)	Years of keeping the taxon	Breeding the taxon in the years
Scaphiophryne brevis (LC)	2007–2008	
Scaphiophryne calcarata (LC)	2011	
Scaphiophryne gottlebei (EN)	2005–2010	
Scaphiophryne madagascariensis (NT)	2006–2014	
Scaphiophryne marmorata (VU)	2004, 2006–2021	2008–2009, 2017, 2020
Scaphiophryne spinosa (LC)	2008	

One could object that the results are not very satisfying. However, it should be mentioned that many species were obtained only as single individuals or of the same sex and we were never able to pair them. This is mainly true for Malagasy frogs and snakes. It is necessary to mention that many chameleons were kept only shortly after confiscation in 2016. Natural history of many taxa of both amphibians and reptiles was and still is poorly known. At the beginning, our breeding methods were more trial and error. Nowadays, much more information is available

Fig. 2: Pregnant female *Grandidierina fierinensis*. Photo: Tomáš Peš jr

Fig. 3: Critically endangered Spider Tortoise (*Pyxis a. arachnoides*) is bred in Pilsen zoo since 2005 but all hatchlings were males until now. Photo: Tomáš Peš jr

Fig. 4: Endangered *Scaphiophryne gottlebei* from Isalo Massif usually lives only 2 years in the wild (Guarino et al, 2010). One wild born specimen has lived 5Y, 7M, 26D in Pilsen zoo. Photo: Jaroslav Vogeltanz

Fig. 5: Wild born *Cophyla grandis* has lived 4 Y, 7 M, 5 D in the Pilsen Zoo. Photo: Jaroslav Vogeltanz

about captive breeding of more and more taxa, especially by private breeders. We are trying to both utilise our own experience as well as the experience of other breeders. Observation and recording of the biological data of captive animals is sometimes the only way to obtain them (Figs 2, 3).

Longevity is also a sign of successful keeping of species in human care. There are only a few published data on the longevity of species from the Indian Ocean islands region (Guarino et al., 1998; Guarino et al., 2010; Jovanovic & Vences, 2010; Tessa et al., 2017a; Tessa et al., 2017b). As historically, not all specimens were possible to identify, in Tab. 2 we only publish data about animals exactly determined. The endangered *Scaphiophryne gottlebei* from Isalo Massif usually lives only 2 years in the wild (Guarino et al., 2010). One wild born specimen has lived 5Y, 7M, 26D in Pilsen Zoo (Fig. 4). A wild born *Cophyla grandis* has lived 4Y,7M, 5D in Pilsen Zoo (Fig. 5).

Since 2019, we have been actively trying to improve breeding conditions. Several species were paired for the first time. A new type of terraria was furnished with better lighting and local heating. A larger number of rearing terraria with non-transparent glass walls allowed us to rear a higher number of reptile hatchlings (Fig. 6). It‘s especially important for day geckos of the genus *Phelsuma*, which are stressed by the presence of conspecific individuals. That can lead to slower growth or even to death. The diet of several species was also changed either in quantity or in composition in accordance with the seasons.

All these changes resulted in a better breeding success in at least some taxonomic groups. Part of the taxa has never been bred before in Pilsen. This can be demonstrated well on the example of the Scincidae family. Not a single specimen of Malagasy skinks was born in Pilsen in the past. In 2021, we managed to reproduce three different taxa. In 2020, we obtained one pair of large aquatic *Amphiglossus reticulatus* from the northwest of Madagascar. This species was quite picky when it came to food. At the beginning, they only ate shrimps. After a few months they also accepted adult crickets. In 2021, we observed the female basking under the heat source much more often than before. These observations indicated possible gravidity. After three months the female laid four eggs with an almost transparent eggshell. Two were fertile and only one hatched five days later. The neonate measured SVL=50.4 mm and weighed 2.2 grams (Fig. 7). *Brachyseps macrocercus* gave birth to three neonates with SVL=30.9–31.3 mm

Tab. 2: Longevity records of amphibians and reptiles in the Zoological and Botanical Garden of the Town Pilsen. (date = YYYY-MM-DD, U = undetermined; M = male; F = female; CB = captive born; WB = wild born).

Taxon	Sex	Origin	Arrival at the Zoo (Date of birth)	Death, Departure	Age
AMPHIBIA					
Cophyla grandis	U	WB	2006-04-11	2010-12-06	4Y,7M, 5D +
Scaphiophryne gottlebei	U	WB	2004-05-28	2010-01-27	5Y, 7M, 26D +
REPTILIA					
Acrantophis dumerili	M	CB	1997-03-27	Alive	24Y, 7M, 5D +
Acrantophis dumerili	F	CB	1997-03-27	Alive	24Y, 7M, 5D +
Acrantophis madagascariensis	F	CB	2005-07-07 (2003-07-28)	Alive	18Y,3M, 4D
Brachyseps macrocercus	U	WB	2011-03-24	2020-07-21	9Y, 3M, 27D +
Blaesodactylus antongilensis	F	WB	2008-05-30	Alive	13Y, 5M, 2D +
Leioheterodon geayi	M	WB	2006-02-07	2014-10-29	8Y, 8M, 22D +
Leioheterodon madagascariensis	F	WB	1993-05-24	2008-03-17	14Y, 9M, 22D +
Leioheterodon modestus	M	WB	1993-05-24	2009-01-15	15Y, 7M, 22D +
Leioheterodon modestus	F	WB	2006-02-07	Alive	15Y, 8M, 25D +
Madagascarophis colubrinus pastoriensis	M	WB	2006-05-06	Alive	15Y, 5M, 26D +
Madagascarophis colubrinus pastoriensis	M	WB	2006-05-06	Alive	15Y, 5M, 26D +
Oplurus quadrimaculatus	F	WB	2014-12-13	Alive	6Y, 10M, 19D +
Phelsuma inexpectata	F	CB	2011-04-27	Alive	10Y, 6M, 5D
Phelsuma madagascariensis boehmei	F	WC	2008-01-05	2018-08-03	10Y, 6M, 29D +
Phelsuma robertmertensi	F	CB	2009-09-14 (ca. 2009-05-01)	2021-03-01	11Y, 10M, 0D
Phelsuma seippi	F	CB	2014-04-26	Alive	7Y, 6M, 6D
Pseudoxyrhopus quinquelineatus	M	WC	2006 -04-11	Alive	15Y, 6M, 21D +
Sanzinia m. madagascariensis	M	CB	1997-02-03	2018-01-29	20Y, 11M, 26D
Sanzinia m. volontany	F	CB	2003-08-15	alive	18Y, 2M, 17D
Sanzinia m. volontany	M	CB	1998-01-21	2020-05-29	22Y, 4M, 8D
Zonosaurus maximus	F	WB	2006-04-11	2014-07-28	8Y, 3M, 17D +
Zonosaurus quadrilineatus	M	WB	1996-05-01	Alive	25Y, 6M, 0D +
Zonosaurus trilineatus	M	WB	2010-02-20	Alive	11Y, 8M, 12D +

Fig. 6: The new type of terraria was furnished with non-transparent glass walls. Photo: Tomáš Peš jr

Fig. 7: *Amphiglossus reticulatus* hatched after 5 days incubation. Photo: Jaroslav Vogeltanz

Fig. 8: *Brachyseps macrocercus* gave birth to three neonates. Photo: Jaroslav Vogeltanz

and weight 0.41–0.49 grams (Fig. 8). This species can be very aggressive between conspecifics. This behaviour was present also between neonates, therefore they had to be separated and raised individually. *Trachylepis elegans* was the third species bred in 2021. This diurnal species very much appreciated the new full spectrum lamp and were much more active. Two clutches of three and four eggs were found and all seven individuals hatched.

Representatives of the family Gerrhosauridae reproduced only sporadically in the past. Keeping of specimens from genus *Zonosaurus* began in 1998 represented by the *Zonosaurus laticaudatus* and *Zonosaurus quadrilineatus.* These species are still being kept today. In the following years more species came to the zoo (8 spp. in total). It seems that these lizards are quite hardy and can live for years in captivity (Table 2). Despite the fact that keeping these lizards is relatively easy, breeding them can be quite tricky and challenging. So far, we have bred three species (*Z. laticaudatus*, Z. *karsteni*, Z. *madagascariensis*). After years of keeping them in the same conditions all year round we tried to mimic conditions during both dry and humid seasons on Madagascar and we provided them with full spectral high intensity light bulbs. The seasonal changes were done mainly by setting different humidity levels in the tanks and by feeding them various fruits and insects during the wet season in contrast to feeding them with only crickets in the dry period. This change of conditions resulted in several successful breedings between 2018 and 2021. In our experience smaller species (i.e. *Z. karsteni*, Z. *madagascariensis*) lay 3–4 eggs on average while the *Zonosaurus laticaudatus* lay 4–6 eggs. Incubation of eggs half submerged in vermiculite in 24 and 28 °C resulted in healthy hatchlings. Raising the young was unproblematic. The only issue could be fatal aggression between individuals, therefore we always keep hatchlings separately. Interspecific aggression in adulthood is also common, especially between males.

Geckos of the genus *Phelsuma* are undoubtedly one of the more commonly seen lizards in zoos. Their diurnal activity together with their attractive appearance could be the reason behind it. Zoo Pilsen is not an exception with 40 species of this genus kept between 1998 and 2021 (Tab. 1). Sadly, despite the huge number of species in captivity, only a few most common species are present in European zoos. Some of the species are threatened in the wild (Tab. 1) and should get more attention in the captive breeding than for example the widely distributed *Phelsuma grandis*. In our zoo, most of the species are kept behind the scenes in three rooms with different ambient temperatures. The first room has its ambient temperature at 28 °C with a slight night drop. Most species from Mascarenes, Comoros archipelago, Pemba Islands and warm parts of Madagascar are kept here. *Phelsuma andamanense* is regularly bred there (Fig. 9). The Andaman day gecko is endemic to the Andaman Archipelago located ca. 6,000 km away from Madagascar, where the genus *Phelsuma* most likely evolved. It is the most basal extant member of the genus (Mohan et al., 2020). Another room with similar conditions houses most of our *Phelsuma* hatchlings and a part of animals used for our research project. In the third room we focus on species which experience lower day temperatures and a more intensive night temperature drop in the wild. That means 24 °C during the day and 17 °C at night. There is a well-known problem with breeding day geckos, their low numbers of male offspring. This is being attributed to temperature dependent sex determination (Gamble, 2010). Despite the large amount of *Phelsuma* species in captivity, there

Fig. 9: *Phelsuma andamanensis* is regularly bred in the warmer breeding room. Photo: Jaroslav Vogeltanz

Fig. 10: We observed pairs of *Boophis rappiodes* in amplexus but they never laid eggs. Photo: Tomáš Peš jr

Fig. 11: Wild born *Boophis rappioides* female was full of eggs on arrival, but we did not observe her laying eggs. Photo: Tomáš Peš jr

Fig. 12: *Guibemantis liber* laid eggs in 2020. Unfortunately, tadpoles did not develop. Photo: Tomáš Peš jr

is still insufficient research on whether they really have this type of sex determination. We have already been cooperating on research for the past three years with the faculty of science of Charles University in Prague focused on *Phelsuma laticauda* and *Phelsuma nigristriata* and their sex determination. We let the eggs incubate in three different temperatures and then look on resulting sex ratio of hatchlings from the different incubation temperatures. We also look for other influences of incubation temperature on the phenotype of hatchlings. Already more than one hundred of *P. laticauda* and more than sixty *P. nigristriata* have hatched. Findings from this project could be useful in future breeding efforts of threatened taxa.

For many years we have struggled to breed or even keep the Malagasy frogs alive. Many of these species come from highly elevated areas (Glaw & Vences, 2007). And these species need low temperatures in captivity as well. Another problem was with stimulation for breeding especially in the genus *Boophis*. All attempts to breed different *Boophis* species failed until now. We observed pairs in amplexus, e.g. in *Boophis albilabris* and *Boophis rappiodes* (Fig. 10), but they never laid eggs. A wild born *Boophis rappioides* female was full of eggs on arrival (Fig. 11), but we did not observe her laying eggs. Controlled climatic conditions and seasonality are very important for breeding reptiles and amphibians. It seems that air pressure plays a very important role when breeding frogs. We use rain chambers, but it would be useful to also try chambers with controlled air pressure like they are in use at Tiergarten Schönbrunn (Weissenbacher, pers. comm.). Keepers in AKVA TERA have regularly been breeding *Dyscophus guinetii* and *Scaphiophryne marmorata* and they have already reared the third generation (Doxanský & Berec, 2010). The only other species that has been bred for years is *Heterixalus alboguttatus*. Active seasonal change with the use of a rain chamber resulted in the first ever laid clutch of small arboreal *Guibemantis liber* in 2020 (Fig. 12). Unfortunately, tadpoles did not develop. The biggest change in breeding success was realised with the threatened terrestrial species of the genus *Mantella*. Representatives of this genus have been present in Pilsen Zoo since 2001 until today. Seven species have been kept here throughout the years. In the past the breeding success was very low. Everything changed two years ago when we changed the breeding conditions. It was based on the experience of other breeders and conditions in the natural habitats. We provide our frogs with a dry season with a shorter day and a low humidity period for four months followed by a wet season when we spray their terraria several times a day. Also, the amount of food is higher during the breeding season. Males respond to this change rapidly usually in a few days after, with calling. We were able to get more than two hundred offspring of *Mantella viridis* during 2020–2021 from our four founder animals and more than one hundred *M. expectata* from our breeding pair in the same period. We already distributed both species which are listed as endangered to six European zoos.

Discussion

Breeding ex-situ is an important tool in saving species from extinction (Zippel et al., 2011). We are still in the beginning of breeding many less-known species. Many of these species are threatened and it is necessary to put in effort to improve our work. Only then we can become real modern arks for such species (Ziegler & Rauhaus, 2019). As the example from Pilsen Zoo shows, an active approach to breeding a specific group of animals can bring results.

Our breeding facility is space limited, so finding responsible recipients for the offspring and further cooperation is necessary for the future development of captive populations. Establishing long-term breeding populations without a larger number of breeding facilities is difficult or even impossible. There is an advantage of possible better adaptation of island species to effects of genetic processes occurring in small populations, e.g. bottleneck etc. (James et al., 2016). Therefore, starting breeding programmes even with a small number of founders should be worth a try.

Zusammenfassung

Der Zoologische und Botanische Garten der Stadt Pilsen ist auf die Flora und Fauna der Inseln spezialisiert. Die Geschichte der Haltung und Zucht von Amphibien und Reptilien aus Madagaskar und den Inseln des Indischen Ozeans wird zusammen mit Anmerkungen zur Biologie einiger Arten vorgestellt. In den Jahren 1998 bis 2021 hat der Zoologische und Botanische Garten der Stadt Pilsen 143 Reptilien- und 43 Amphibienarten aus dieser Region gehalten. In dem genannten Zeitraum haben sich 60 Reptilien- und 9 Amphibienarten erfolgreich fortgepflanzt. Wir präsentieren auch einige interessante Daten über die Langlebigkeit der einzelnen Tiere.

References

AmphibiaWeb. (2021). University of California, Berkeley. https://amphibiaweb.org [Accessed on 16th November 2021].

Cheke, A., & Hume, J. P. (2010). Lost land of the dodo: the ecological history of Mauritius, Réunion and Rodrigues. Bloomsbury Publishing.

Doxanský, J., & Berec, M. (2010). *Scaphiophryne marmorata*. Care and breeding of the Green Burrowing Frog at the Pilsner Zoo. Reptilia, 67, 53–59.

Gamble, T. (2010). A review of sex determining mechanisms in geckos (Gekkota: Squamata). Sexual Development, 4(1–2), 88–103.

García, G., Bock, L., Earle, S., Berridge, R., & Copsey, J. (2008). Captive breeding as a tool for the conservation of Malagasy amphibians: how ready are we to respond to the need. A Conservation Strategy for the Amphibians of Madagascar. Monografie XLV. Museo Regionale Di Scienze Naturali, Torino, Italy, 321–342.

Glaw, F., & Vences, M. (2007). A field guide to the amphibians and reptiles of Madagascar. Third Edition. Verlag.

Guarino, F. M., Andreone, F., & Angelini, F. (1998). Growth and longevity by skeletochronological analysis in *Mantidactylus microtympanum*, a rain-forest anuran from southern Madagascar. Copeia, 1998(1), 194–198.

Guarino, F. M., Tessa, G., Mercurio, V., & Andreone, F. (2010). Rapid sexual maturity and short life span in the blue-legged frog and the rainbow frog from the arid Isalo Massif, southern-central Madagascar. Zoology, 113(6), 378–384.

IUCN. (2021). The IUCN Red List of Threatened Species Version 2019-3. http://www.iucnredlist.org [Downloaded on 16th November 2021].

James, J. E., Lanfear, R., & Eyre-Walker, A. (2016). Molecular evolutionary consequences of island colonization. Genome Biology and Evolution, 8(6), 1876–1888.

Jenkins, R. K. B., Tognelli, M. F., Bowles, P., Cox, N., Brown, J. L., Chan, L., … others. (2014). Extinction risks and the conservation of Madagascar's reptiles. PLoS One, 9(8), e100173.

Jovanovic, O., & Vences, M. (2010). Skeletochronological analysis of age structure in populations of four species of Malagasy poisonous frogs, genus *Mantella*. Amphibia-Reptilia, 31(4), 553–557.

Mohan, A. V, Orozco-terWengel, P., Shanker, K., & Vences, M. (2020). The Andaman day gecko paradox: An ancient endemic without pronounced phylogeographic structure. Scientific Reports, 10(1), 1–17.

Rahbek, C. (1993). Captive breeding—a useful tool in the preservation of biodiversity? Biodiversity & Conservation, 2(4), 426–437.

Tessa, G., Crottini, A., Giacoma, C., Guarino, F. M., & Randrianirina, J. E. (2017). Comparative longevity and age at sexual maturity in twelve rainforest frogs of the genera *Boophis*, *Gephyromantis*, and *Mantidactylus* (Anura: Mantellidae) from Madagascar. Phyllomedusa: Journal of Herpetology, 16(1), 13–21.

Tessa, G., Glaw, F., & Andreone, F. (2017). Longevity in *Calumma parsonii*, the World's largest chameleon. Experimental Gerontology, 89, 41–44.

Uetz, P., Freed, P., Hošek, J. (2021). The Reptile Database. http://www.reptile-database.org [Downloaded on 16th November 2021].

Ziegler, T., & Rauhaus, A. (2019). Der Beitrag des Kölner Zoos zur Erhaltung der Amphibienvielfalt: Nachzucht-, Forschungs-und Schutzprojekte. Zeitschrift Des Kölner Zoos, 62, 79–104.

Zippel, K., Johnson, K., Gagliardo, R., Gibson, R., McFadden, M., Browne, R., … others. (2011). The Amphibian Ark: a global community for ex situ conservation of amphibians. Herpetological Conservation and Biology, 6(3), 340–352.

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Threatened Malagasy amphibians and reptiles in zoos – a call for enhanced implementation of the IUCN's One Plan Approach

Bedrohte Amphibien und Reptilien aus Madagaskar in Zoos – ein Aufruf zur verstärkten Umsetzung des „One Plan Approach" der Weltnaturschutzunion (IUCN)

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Abstract

Madagascar is home to 370 native amphibian and 420 native reptile species with an extraordinary high endemism rate of approx. 98%. Less than half (39%) of Madagascar's amphibian and less than a third (32%) of Madagascar's reptile species are currently evaluated as threatened by the IUCN (2021). We investigated for which threatened endemic Malagasy amphibian and reptile species ex situ populations in zoological institutions already exist,

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and which threatened species are not yet covered by ex situ conservation measures. We thus have surveyed species kept in zoological institutions, analysed the number of species held, the number of individuals per species, the number of zoos keeping a species, and those with breeding success in the past 12 months by retrieving data from the Zoological Information Management System (ZIMS, 2021). These data were supplemented with data from the European database Zootierliste (ZTL). In addition, a richness analysis was performed to find out how zoos keeping Malagasy amphibian and reptile species are distributed at a global scale. According to our analysis of ZIMS data, only 36 endemic Malagasy amphibian species (9.7%) (37 if considering data from ZTL database) are globally kept in zoos. Ten of them are threatened, which amounts to only 6.9% of the 145 endemic and threatened Malagasy amphibian species. As such, it is likely that more than 93% of the threatened endemic Malagasy amphibian species (135) currently do not benefit of any ex situ conservation component. Our analysis revealed that there is a higher percentage on Malagasy reptile species kept in zoos in comparison to amphibians. Considering both, ZIMS and ZTL analyses, 97 endemic Malagasy reptile species (23%) are globally kept, 27 of which are threatened, which amounts to 20% of the 133 endemic Malagasy reptile species that are threatened. This implies that 80% of the threatened endemic reptile species (106) from Madagascar currently have no ex situ conservation component at the time of this survey. Of the 36 endemic Malagasy amphibian species and the 87 endemic reptile species kept in ZIMS zoos worldwide, only eleven amphibian species (30.5%) and 34 reptile species (39%) have reproduced within the last 12 months. Finally, only four (36%) of the bred amphibian species are threatened taxa, and of the reptile species bred, only thirteen (38%) are threatened. Only zoos in Europe and North America are currently playing a major role in keeping Malagasy herpetofauna. To optimise management and conservation efforts in zoos, refocusing on threatened and micro-endemic species, and reviewing their stocks accordingly is highly recommended. In-country ex situ approaches have already been started for amphibians and reptiles. However, extension of insurance populations among various institutions abroad should be seen as an essential contribution to be better prepared for catastrophic events potentially affecting local facilities or natural populations. Together such a strategy complies with the One Plan Approach proposed by the IUCN SSC Conservation Breeding Specialist Group (CBSG), viz. the development of management strategies and conservation actions by all responsible parties for all populations of a species, whether inside or outside their natural range. With this analysis we aim to provide a basis for improved ex situ conservation breeding measures and develop a conservation breeding network for the threatened endemic species of the Malagasy herpetofauna.

Keywords: conservation breeding, herpetofauna, Madagascar, One Plan Approach, ZIMS/ZTL analyses

Introduction

Madagascar, situated 400 km east of Africa, is the fourth largest island of the world, after Greenland, New Guinea and Borneo (Benstead et al., 2003). It has been isolated for the last 88 million years (Ali & Huber, 2010; Ali & Vences, 2019), despite speculations about subaerial terrestrial causeways in the Cenozoic (Masters et al., 2020). Madagascar thus has a unique flora and fauna characterised by high level of endemism. More than 90% of 12000 vascular plants are only found in Madagascar. 50% of the birds, 98% of reptiles and all native amphibians and mammals are endemic (Goodman & Benstead, 2003; Ganzhorn et al., 2008).

Madagascar also has diverse biomes characterised by distinct climatic conditions, resulting in a large variety of different habitats. Accordingly, many species are restricted to small distribution ranges only, e.g. a tiny rock island or a single forested region (Wilmé et al., 2006; Ganzhorn et al., 2016). These micro-endemic species are particularly threatened with extinction because their habitats can be degraded or destroyed very quickly, often before conservation measures can be implemented (Passal, 2015).

Humans may have colonised Madagascar more than 10000 years ago (Henderson et al., 2018). Since then, Madagascar‘s unique biodiversity became substantially affected by anthropogenic changes (e.g. Burney et al., 2003; Burney & Flannery, 2005; Morelli et al., 2020). As a result of the degradation of woody vegetation caused by human colonisation and the expansion of the pantropical savanna that started in the late Miocene (Strömberg, 2011), the central highlands are currently dominated by a grassland-woodland mosaic, where grasslands are mixed with agricultural land, shrubland and patches of woodland (Benstead et al., 2003; Ganzhorn et al., 2016). Changes in the vegetation have also reached the eastern rainforest belt, which had already been reduced to 50–60% of its original extent (Harper et al., 2007) resulting in an estimated reduction of nearly 80% of the former Malagasy woodlands and forests (Harper et al., 2007). In total, the estimated habitat loss of Madagascar is about 90% (Lowry et al., 1997). However, nearly 90% of the Malagasy endemic fauna occur in the forests of the island (Dufils, 2003). Besides deforestation, large parts of woodland are expected to disappear over time due to climate change, especially the littoral forests (Virah-Sawmy, 2009; Watson et al., 2010). Based on the diversity of species, continuous loss of habitat and exceptionally high rate of endemism, Madagascar has been recognised as one of the global hotspots for biodiversity conservation (Groombridge & Jenkins, 1998; Myers et al., 2000; Ganzhorn et al., 2008). With a considerable number of endemic species, which need priority in conservation, and the loss of the approx. 90% of native forest cover, Madagascar is among the five most important of the global hotspots of biodiversity (Myers et al., 2000).

Hunting and the illegal trade of wild animals is threatening biodiversity as well (Barrett & Ratsimbazafy, 2009; Auliya et al., 2016; Marshall et al., 2020). Emerging infectious diseases such as chytridiomycosis caused by the amphibian chytrid fungus *Batrachochytrium dendrobatidis*, are another threat (Bletz et al., 2015), as well as the rapidly expanding population of the invasive Asian Toad *Duttaphrynus melanostictus* (Licata et al., 2019, 2020), which due to the vulnerability of nearly all Malagasy vertebrates to its toxins, is forecasted to represent a serious threat for its potential predators (Marshall et al., 2018; Licata et al., 2022). The initiative “A Conservation Strategy for the Amphibians of Madagascar” (ACSAM) was developed shortly after the IUCN Species Survival Commission Amphibian Specialist Group (ASG) in 2006 (Andreone et al., 2008). This initiative had the aim to organise a response to the multiple threats faced by the native amphibian communities of Madagascar, however, despite progresses such as the establishment of the country’s first amphibian captive breeding centre at Andasibe (Edmonds et al., 2015), the formation of the national Chytrid Emergency Cell and the establishment of the preemptive national chytrid monitoring programme (Weldon et al., 2013), the creation of new Protected Areas designed chiefly to protect some Critically Endangered amphibians and reptile species (e.g. the Manjakatompo Ankaratra and the Mangabe-Ranomena-Sahasarotra protected areas), and several campaigns focussed on the study of some iconic species (e.g. Andreone et al., 2013; Crottini et al., 2008, 2012; 2019), the conservation situation for Madagascar’s amphibians remains critical (Andreone et al., 2012; Ndriantsoa et al., 2018).

When in situ conservation is under difficult circumstances, e.g. if in situ protection is implemented too slowly and not sufficient to prevent habitat loss and species from extinction, ex situ conservation approaches can be an additional helpful conservation measure

(Benstead et al., 2003; Farhadinia et al., 2020) until threats and problems in natural habitats are resolved. Undoubtedly, there is urgency for habitat conservation management measures to prevent extinctions, but for species immediately threatened with extinction, ex situ conservation breeding can be the only reliable means to save them from extinction (Benstead et al., 2003; Loiselle, 2003). Zoos can contribute as major conservation centres with global networks by preserving viable species populations, which would be threatened with extinction due to increased habitat loss in the wild, or by the adversing effect of emerging infectious diseases or invasive species (Wayre, 1969; Conde et al., 2011; Conde, 2013). Leiss et al. (2021) have recently reviewed threatened Malagasy freshwater fishes in zoos and aquaria and highlighted the need for the establishment of an ex situ conservation network.

The current study aims to investigate for which threatened endemic Malagasy amphibian and reptile species ex situ populations in zoological institutions already exist, and which threatened species are not yet covered by ex situ conservation measures. Garcia et al. (2008) already developed an overview on the status of threatened amphibians in captive facilities (Andreone, 2008) and the current amphibian analysis represents an update of that data. In this study, we have surveyed Malagasy amphibian and reptile species kept in zoological institutions by retrieving data from the Zoological Information Management System (ZIMS, 2021). We completed the data with data from the European database List of Zoo Animals ("Zootierliste", ZTL). By doing so, we aim at providing a basis for improved ex situ conservation breeding measures for the threatened endemic species of the Malagasy herpetofauna.

Material and Methods

A list of currently described Malagasy amphibian and reptile species was compiled based on Glaw & Vences (2007) updated by Frost (2021), AmphibiaWeb (2021) and Uetz et al. (2021). Species not yet scientifically named were not considered.

Species were classified as "introduced" (i.e. not naturally occurring in Madagascar), "native" (naturally occurring in Madagascar but also elsewhere) and "endemic" (only occurring in Madagascar). Introduced species were excluded from all further analyses.

The conservation status of each species according to IUCN (2021) was added. The species that were categorized as Vulnerable (VU), Endangered (EN) and Critically Endangered (CR), by IUCN (2021) were considered as "threatened". Additional IUCN categories were Extinct (EX), Extinct in the wild (EW), Near Threatened (NT), Data Deficient (DD), Not Evaluated (NE) and Least Concern (LC).

To gain an overview of native Malagasy amphibian and reptile species globally held in zoos, similarly to what was performed by Leiss et al. (2021) for fishes, we collected and analysed the number of individuals kept, the number of keeping institutions, and successful reproduction within the last 12 months based on information retrieved from the ZIMS (2021) database, which provides information on individuals kept in zoos as well as some animals held in other zoological institutions such as conservation centres. It must be taken into account that breeding success does not correspond to actual reproduction potential, as only surviving individuals are accounted and e.g. the European Association of Zoos and Aquaria (EAZA) sometimes does not recommend breeding (see discussion for details). The ZIMS analysis for amphibians was performed in September 2021 and for reptiles in October 2021. The ZIMS list may miss some captive populations or breeding records, as some data may be obsolete or have not (yet) been entered in the database, while it is also important to note that some zoos do not use ZIMS.

Again, similarly to what has been performed by Leiss et al. (2021), and to increase the coverage of our data set, we cross-checked the data collected from the ZIMS database with information available on the website "Zootierliste" (ZTL, List of Zoo Animals: https://zootierliste.de/), which includes animal collections of additional institutions in Germany and Europe as well as some private zoos, rescue centres and other facilities (Graf et al., 2021). ZTL data were only analysed in our overall summary of species present in institutions as most ZTL data are based on entries that can have up to four years ago and thus are of limited relevance when quantifying current animal collections.

Geographic analyses were performed in R to identify focal regions in the keeping of Malagasy amphibians and reptiles. Coordinates of the relevant zoos were retrieved from ZIMS. Based on the number of specimens per species kept in each zoo we computed the total number of zoos per country as well as the following biodiversity indices using the package vegan (Oksanen et al., 2020): the Shannon-Weaver Index ($H = -\sum p_i \log(b)\, pi$), and two versions of the Simpson Index ($D = \sum p_i^2$) with 1-D and the inverse Simpson Index with 1/D. In these formulas p_i represents the relative proportion of species, i and b represent the natural logarithm (b=2 herein). Furthermore, Pielou's evenness (J) was computed as J = H/log(n), wherein n represents the total number of species.

Results

Species diversity and threat evaluation of Malagasy amphibians

372 amphibian species are reported to occur in Madagascar (Frost, 2021). Except the dicroglossid anuran *Hoplobatrachus tigerinus* and the bufonid *Duttaphrynus melanostictus*, both introduced in Madagascar and evaluated by the IUCN (2021) as Least Concern, 370 amphibian species are endemic to Madagascar. The most species-rich family is Mantellidae with a total of 233 species of which 230 are endemic to Madagascar, whereas three species of the family are endemic to the Comoros. Of the endemic amphibian species of Madagascar (including Mantellidae, Microhylidae, Hyperolidae and Ptychadenidae), 145 (39%) are threatened: 21 Critically Endangered, 80 Endangered, and 44 Vulnerable (IUCN, 2021). Of the remaining 225 endemic amphibian species, 153 species (41%) are evaluated as Near Threatened (n = 18) and as Least Concern (n = 135), another 72 species (20%) are either Data Deficient (n = 13) or Not Evaluated (n = 59) (IUCN, 2021) (Fig. 1).

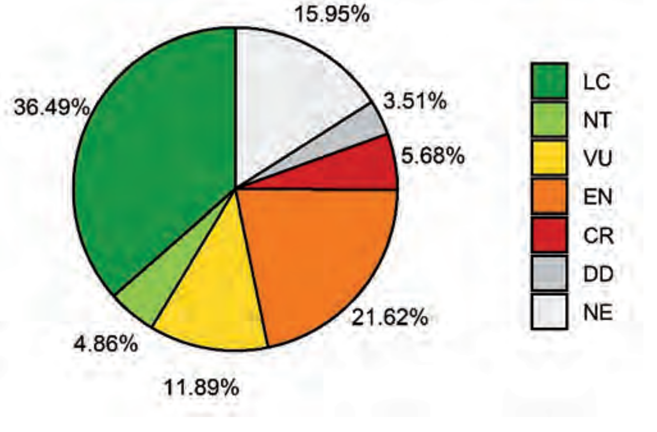

Fig. 1: Threat status of endemic Malagasy amphibian species (n = 370) according to IUCN (2021).

Endemic Malagasy amphibian species globally held in zoological institutions according to ZIMS

Of the 370 endemic Malagasy amphibian species, only 36 species (9.7%) are currently kept in zoos worldwide (Tab. 1). Of the kept species, only 10 (27.8%) are threatened (Tabs. 1–2): one Critically Endangered, four Endangered, and five Vulnerable (IUCN, 2021). This amounts to only 6.9% of the 145 endemic Malagasy amphibian species that are threatened. Three endemic Malagasy amphibian species kept in zoos are Near Threatened (*Boophis elenae*, *Mantella pulchra*, *Scaphiophryne madagascariensis*) and the majority is listed as Least Concern (n = 23).

According to ZIMS, the most commonly held species worldwide is *Mantella aurantiaca* with 1035 kept individuals followed by *M. viridis* with 745 animals. Of the mantellid subfamily Mantellinae 17 species are globally held in zoos making Mantellinae the best represented subfamily (ZIMS and ZTL data). The mantellid subfamily Boophinae is represented by eight species, and the subfamily Laliostominae is lacking in zoo collections. Microhylidae are represented by five species of Scaphiophryninae, three species of Dyscophinae, whereas Cophylinae are not kept. Three species of the Hyperoliidae family are kept in total. Species of Ptychadenidae are not kept in zoos.

Tab. 1: Endemic Malagasy amphibian species globally held in zoos according to ZIMS, with number of zoos and total number of individuals kept; * = threatened species according to IUCN (2021).

Species	Zoos	Individuals	Species	Zoos	Individuals
Mantellidae			*Mantella milotympanum**	3	17
Boophinae			*M. nigricans*	2	12
Boophis albilabris	1	8	*M. pulchra*	8	39
B. albipunctatus	1	1	*M. viridis**	26	745
B. elenae	1	9	*Mantidactylus betsileanus*	2	9
B. goudotii	1	1	*M. femoralis*	1	1
B. luteus	2	5	**Hyperoliidae**		
B. madagascariensis	1	4	*Heterixalus alboguttatus*	10	249
B. pyrrhus	1	2	*H. betsileo*	1	5
B. rappiodes	1	4	*H. madagascariensis*	6	30
Mantellinae			**Microhylidae**		
Guibemantis bicalcaratus	1	3	**Scaphiophryninae**		
G. pulcher	1	3	*Scaphiophryne boribory**	1	4
*Mantella aurantiaca**	69	1035	*S. calcarata*	1	2
M. baroni	3	162	*S. gottlebei**	2	4
*M. bernhardi**	1	1	*S. madagascariensis*	4	10
M. betsileo	14	113	*S. marmorata**	5	27
*M. crocea**	1	2	**Dyscophinae**		
M. ebenaui	3	9	*Dyscophus antongilii*	18	82
*M. expectata**	27	369	*D. guineti*	61	739
M. laevigata	12	195	*D. insularis*	4	9
*M. madagascariensis**	7	66			

Endemic Malagasy amphibian species held in European institutions according to ZTL

The ZTL analysis revealed 18 endemic Malagasy amphibian species (in alphabetical order) being kept in European institutions (with number of institutions in brackets): *Dyscophus antongilii* (15), *D. guineti* (41), *Guibemantis liber* (1), *Heterixalus alboguttatus* (6), *H. betsileo* (1), *H. madagascariensis* (1), *Mantella aurantiaca* (21), *M. baroni* (2), *M. betsileo* (8), *M. expectata* (6), *M. laevigata* (1), *M. madagascariensis* (5), *M. nigricans* (2), *M. viridis* (7), *Mantidactylus betsileanus* (5), *Scaphiophryne gottlebei* (1), *S. madagascariensis* (1) and *S. marmorata* (4).

Most of the species belong to the family Mantellidae (Mantellinae). Six of the species listed in ZTL are threatened: four EN and two VU (Tab. 2, Figs. 3–4).

Only one endemic Malagasy anuran species listed in ZTL was not included in the ZIMS database: the mantellid *Guibemantis liber*, which is not threatened (LC) according to IUCN (2021) and held in only one European institution (Plzen Zoo).

Tab. 2: Threatened endemic Malagasy amphibians (IUCN, 2021) held in zoos according to ZIMS (globally) and ZTL (only Europe and not contained in ZIMS).

Species	Threat status	Zoos according to ZIMS (institutions listed if less than 10)	Zoos according to ZTL (not contained in ZIMS)
Mantellidae			
Mantella aurantiaca	EN	69 institutions in 3 regions	- Amsterdam Artis Zoo (Netherlands) - Poznan Zoo (Poland) - Bioparc Fuengirola (Spain) - Plzen Zoo (Czech Republic) - Zájezd Zoopark (Czech Republic)
M. bernhardi	VU	- Detroit Zoo (USA)	
M. crocea	VU	- Museum de Besançon (France)	
M. expectata	EN	27 institutions in 2 regions	
M. madagascariensis	VU	- Museum de Besançon (France) - Wuppertal Zoo (Germany) - Budapest Zoo (Hungary) - Moscow Zoo (Russia) - Fort Worth Zoo (USA) - Pana'ewa Rainforest Zoo & Garden (USA) - Staten Island Zoo (USA)	- Tierpark Senftenberg (Germany) - Poema del Mar (Spain)
M. milotympanum	CR	- Ellen Trout Zoo (USA) - Aquarium & Rainforest and Moody Gardens (USA) - Bronx Zoo (USA)	
M. viridis	EN	26 institutions in 2 regions	
Microhylidae			
Scaphiophryne boribory	VU	- Plzen Zoo (Czech Republic)	
S. gottlebei	EN	- ZooParc de Beauval (France) - Steinhart Aquarium (USA)	
S. marmorata	VU	- Zoo Dvur Kralove (Czech Republic) - Plzen Zoo (Czech Republic) - Parc Zoologique de Paris (France) - Riga Zoo (Latvia) - WWT Slimbridge (UK)	- Helsinki Zoo (Finland)

Fig. 2: Threatened endemic Malagasy amphibians held in zoos: *Scaphiophryne gottlebei* (EN, left, photo: A. Crottini), *S. marmorata* (VU, right, photo: T. Ziegler).

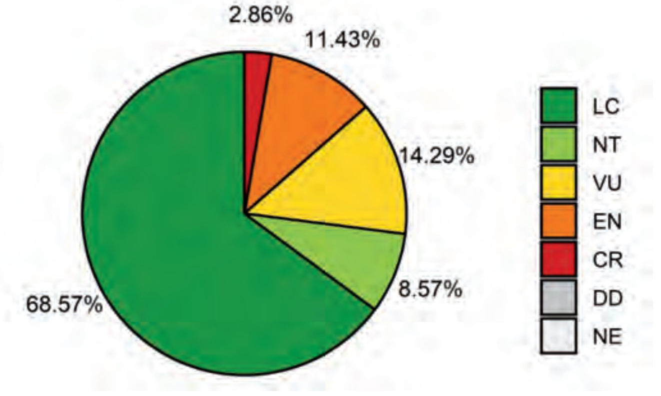

Fig. 3: Threat status (according to IUCN 2021) of endemic Malagasy amphibian species kept in zoos (n = 37, according to ZIMS and ZTL analyses).

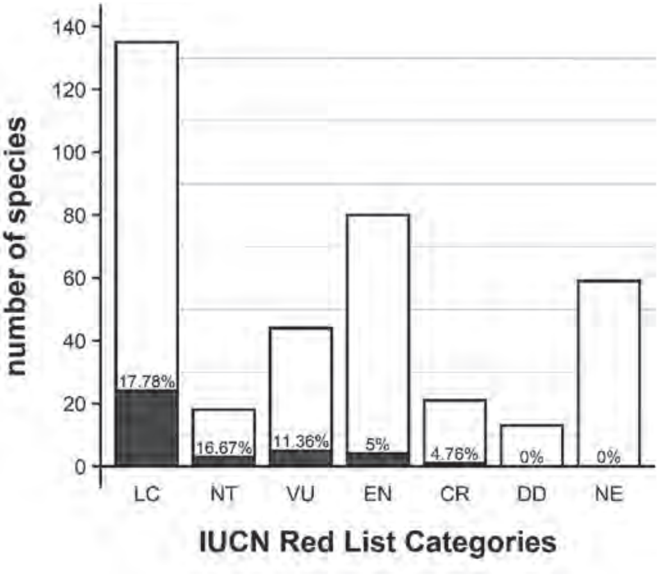

Fig. 4: Endemic Malagasy amphibian species (white) and percentage of endemic Malagasy amphibians globally kept in zoos (dark) organised by threat status (according to ZIMS, ZTL).

Endemic Malagasy amphibian species held in zoos by continents

Endemic Malagasy amphibian species are only recorded from zoos in Africa, Asia, Europe, and North America (Fig. 7, Tabs. 3–4). No zoos are documented from the regions of South America and Oceania/Australia. With 35 kept endemic Malagasy amphibian species, European zoos are leading (ZIMS, ZTL data) followed by North American zoos, where 17 species are held. In Africa one species and in Asia two species are held. These geographic patterns are well reflected in Fig. 5, the highest number of zoos keeping Malagasy amphibians is located in North America and Europe, with vastly varying numbers of individuals and covered diversities. Many of them keep comparably few specimens and a limited diversity, whereas some are more specialised (Figs. 5, 6).

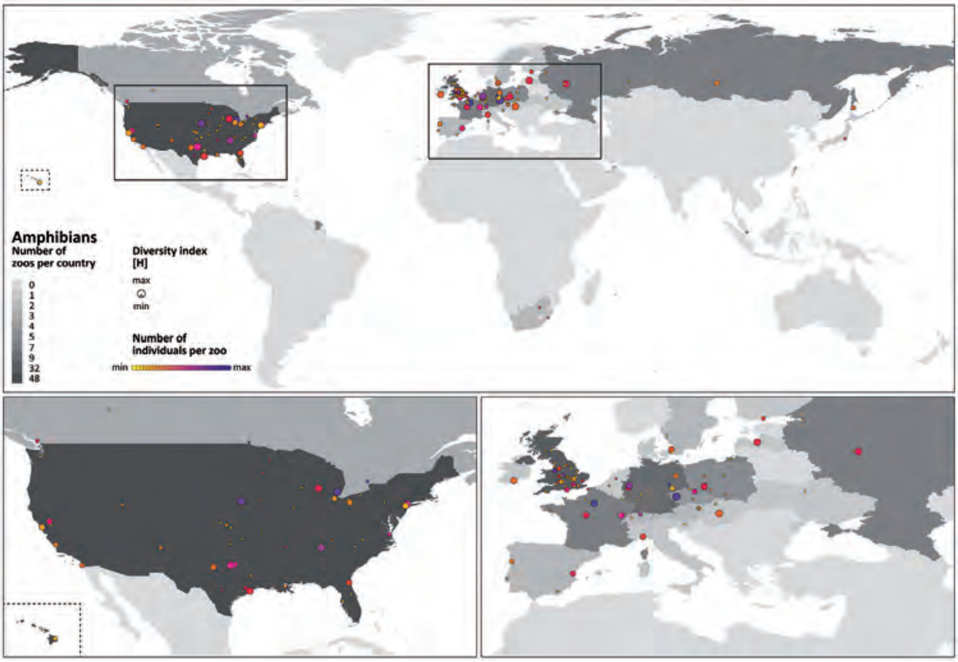

Fig. 5a: Geographic overview of Malagasy amphibians kept in zoos. Countries are coloured according to the number of zoos keeping specimens. Coloured dots represent single zoos, their colours refer to the number of individuals and their sizes code for H = Shannon Weaver Index. Inserts highlight the most relevant areas, i.e. North America and Europe with the highest density of zoos.

According to ZIMS 2168 individuals of endemic Malagasy amphibians are kept in 87 institutions in Europe, 1645 individuals in 54 zoos in North America, 36 individuals in two institutions in Africa and 127 individuals in four institutions in Asia.

The family most commonly kept in North America is Mantellidae with the subfamily Mantellinae, with four species held in Canada and 11 in the USA. In this region, the species most commonly kept is *Mantella aurantiaca* with 317 held individuals. Canada's most commonly kept species is *Dyscophus guineti* with 120 individuals.

The majority of the kept species per continental region is listed as Least Concern, with most being kept in Europe (n = 23), followed by North America (n = 9). Only one species classified as Least Concern is held in Africa. In Asia two species are held, one classified as Least Concern, the other as Endangered (*Mantella aurantiaca*) (IUCN, 2021). Most threatened species are held in Europe (n = 8), which amounts to 23% of the species kept in this region, followed by North America (n = 7), where the percentage of kept threatened species amounts to 41%s (Fig. 8).

North American zoos keep the highest number of Critically Endangered species (1), with *Mantella milotympanum* being held only in the USA. European and North American zoos keep the same number of Endangered species (4). European zoos have more Vulnerable species (4 versus 2).

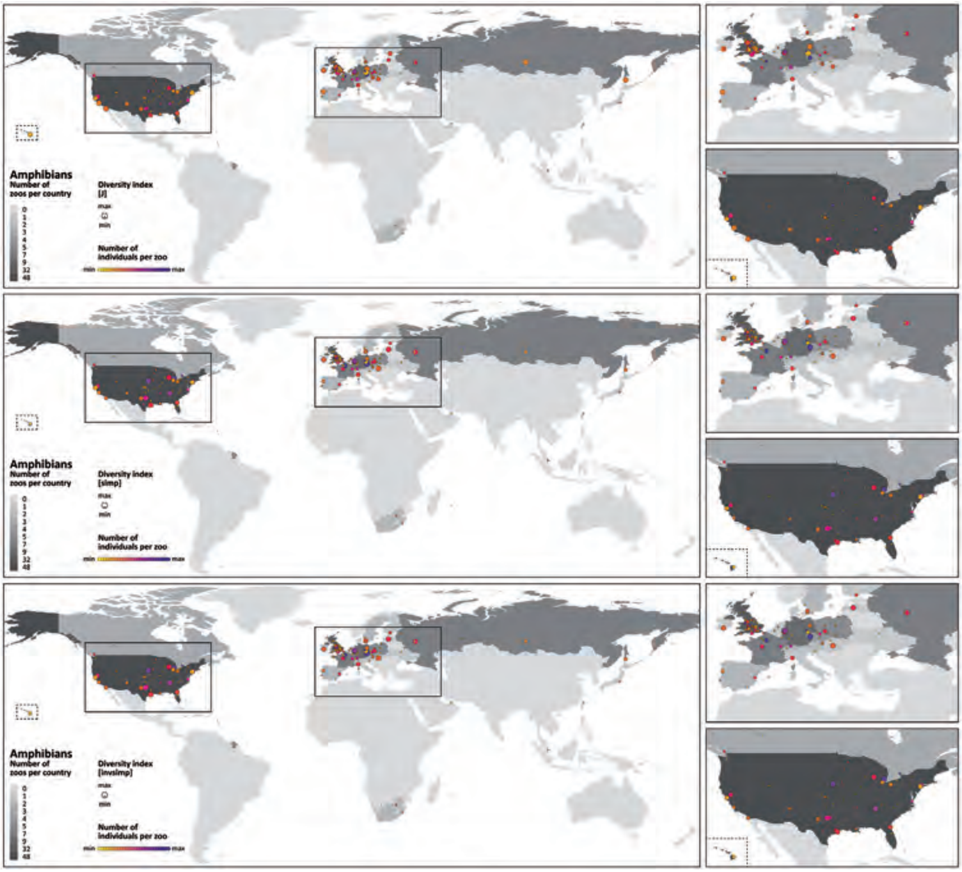

Fig. 5b: Geographic overview of amphibians from Madagascar kept in zoos. Countries are coloured according to the number of zoos keeping specimens. Coloured dots represent single zoos, their colours refer to the number of individuals, and their sizes code for the respective diversity index: J = Pielou's Evenness, simp = Simpson's Index, and invsimp = inverse Simpson Index. Inserts highlight the most relevant areas, i.e. North America and Europe with the highest density of zoos.

Tab. 3: Endemic Malagasy amphibian species globally held in zoos except Europe (according to ZIMS).

	Country	Species held (threatened)	Individuals	Institutions	Zoos with most species held (species number held in brackets)
North America	Canada	6 (2)	151	3	Toronto Zoo (4)
	USA	17 (7)	1483	51	Detroit Zoo (8)
Asia	Japan	2 (1)	34	1	Ueno Zoological Gardens (2)
	Singapore	1 (1)	86	1	Singapore Zoo (1)
	Taiwan	1 (1)	6	1	Taipei Zoo (1)
	United Arab Emirates	1 (1)	1	1	The Green Planet Dubai (1)
Africa	South Africa	2 (0)	36	2	Montecasino Bird Gardens (1) & uShaka Marine World (1)

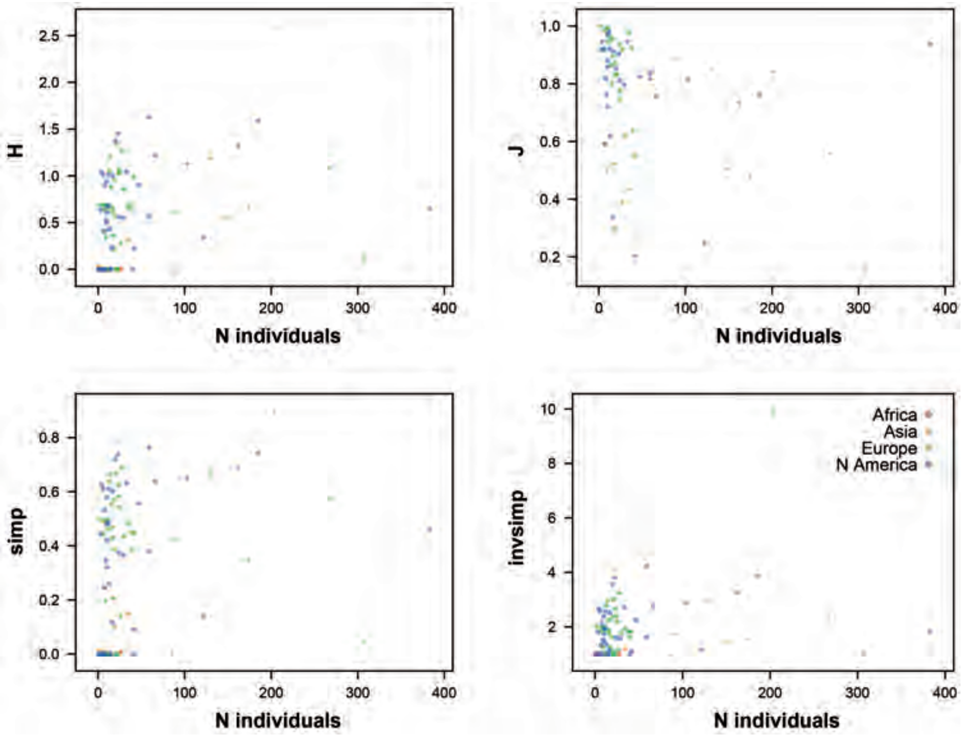

Fig. 6: Diversity of amphibians versus number of individuals per zoo in each continent. H = Shannon Weaver Index, J = Pielou's evenness, simp = Simpson Index, invsimp = Inverse Simpson Index.

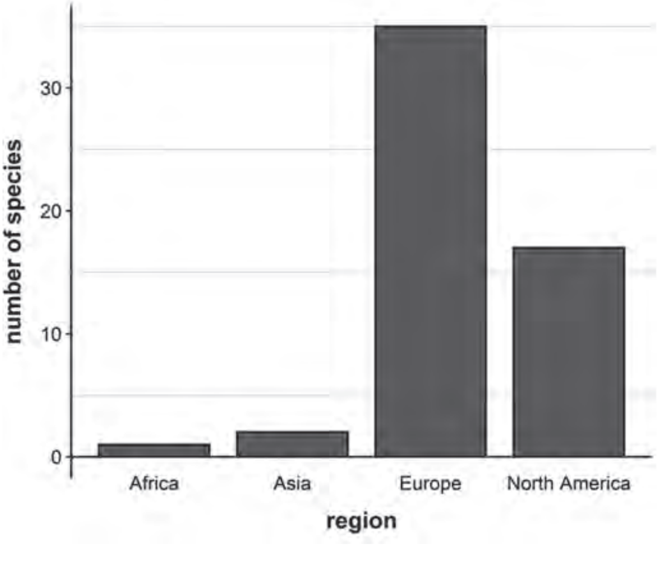

Fig. 7: Number of endemic Malagasy amphibian species kept in zoos by region (according to ZIMS).

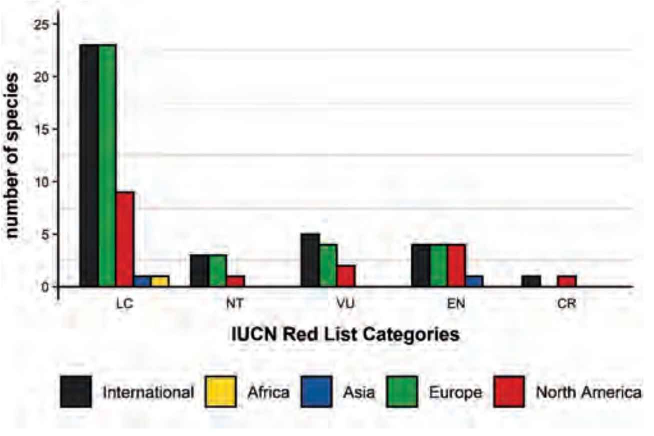

Fig. 8: Threat status of kept endemic Malagasy amphibian species sorted by continental regions (IUCN, 2021); international refers to the number of species kept globally.

Endemic Malagasy amphibian species held in European zoos

According to ZIMS, endemic Malagasy amphibians are kept in 23 European countries (Tab. 4). The species most commonly kept in Europe is *Mantella aurantiaca* (582 individuals in 42 institutions), followed by *Dyscophus guineti* (544 individuals in 35 institutions).

Most species (22) are held in Czech Republic (Plzen Zoo), followed by France (13 species) and the UK (11 species). However, there are only four threatened species kept in Czech Republic, most threatened species (6) being held in France followed by the UK (4). Nine European countries keep only non-threatened endemic Malagasy amphibians.

Tab. 4: Endemic Malagasy amphibian species held in European zoos (according to ZIMS).

Country	Species held (threatened)	Individuals	Institutions	Zoos with most species held (species number held in brackets)
Austria	2 (0)	21	2	Haus des Meeres (2)
Belgium	1 (0)	6	1	Antwerp Zoo (1)
Czech Republic	22 (4)	221	5	Plzen Zoo (22)
Denmark	1 (0)	22	1	Copenhagen Zoo (1)
Finland	2 (1)	16	1	Helsinki Zoo (2)
France	13 (6)	366	6	Parc Zoologique de Paris (7)
Germany	7 (3)	502	10	Wuppertal Zoo (4)
Hungary	4 (2)	14	1	Budapest Zoo (4)
Ireland	3 (2)	13	1	Fota Wildlife Park (3)
Italy	3 (2)	19	1	Acquario di Genova (3)
Latvia	5 (3)	21	1	Riga Zoo (5)
Luxembourg	1 (0)	2	1	Parc Merveilleux (1)
Netherlands	1 (1)	12	1	Dierenpark Amersfoort (1)
Poland	5 (2)	59	5	Wroclaw Zoo (4)
Portugal	2 (0)	18	2	Zoo de Gaia - Zoo Sánto Inacio (2)
Russia	6 (2)	58	5	Moscow Zoo (4)
Slovakia	1 (0)	1	1	Zoologicka zahrada Bojnice (1)
Slovenia	1 (0)	3	1	Zivalski vrt Ljubljana (1)
Spain	5 (1)	57	3	Bioparc Valencia (4)
Sweden	3 (1)	20	3	Tropikariet (3)
Switzerland	2 (0)	91	2	Zurich Zoo (2)
UK	11 (4)	628	32	Chester Zoo (4)
Ukraine	1 (0)	2	1	Kiev Zoological Park (1)

Fig. 9: Threatened endemic Malagasy amphibians listed as Endangered and bred in zoos in the last 12 months: *Mantella aurantiaca* (top, photo: F. Glaw), *M. expectata* (bottom, photo: T. Ziegler).

Most individuals are kept in the UK (628), where also the highest number of institutions (32) can be found, followed by Germany with 502 individuals in 10 institutions and France with 366 individuals in 6 institutions.

Amphibian reproduction success

Of the 36 endemic Malagasy amphibian species globally kept in zoos according to ZIMS, 11 (30.5%) have successfully reproduced within the last 12 months (Fig. 10; Tabs. 5–6). Nine of the 11 bred amphibian species (82%) belong to the anuran family Mantellidae. Four of the 11 bred amphibian species (36%) are threatened species (3 EN, 1 VU) and seven LC (Figs. 11–12; Tab. 5).

The breeding success with the highest number of offspring within the last 12 months was that of *Dyscophus guineti* with 500 bred individuals (all from Parc Zoologique de Paris) (Fig. 12).

Mantella madagascariensis listed as Vulnerable and *M. betsileo* listed as Least Concern had the lowest breeding successes, with two bred individuals each (Fig. 12). Moscow Zoo was the institution with most bred species (4).

Tab. 5: Threatened endemic Malagasy amphibian species (IUCN, 2021) that were successfully bred in zoos within the last 12 months (according to ZIMS).

	IUCN Status	Region	Institutions (12 in total)	Individuals bred (389 in total)
Mantella aurantiaca	EN	Russia	Moscow Zoo	2
		UK	Chester Zoo	76
		Singapore	Singapore Zoo	68
		Taiwan	Taipei Zoo	1
		France	Parc Zoologique de Paris	30
		USA	Virginia Zoological Park	20
			6 (total)	197 (total)
M. expectata	EN	Czech Republic	Plzen Zoo	40
		USA	Dallas Zoo	6
			2 (total)	46 (total)
M. madagascariensis	VU	Russia	Moscow Zoo	2
			1 (total)	2 (total)
M. viridis	EN	Czech Republic	Plzen Zoo	65
		Poland	Wroclaw Zoo	3
		USA	Virginia Zoological Park	49
			Omaha's Henry Doorly Zoo	2
			San Antonio Zoo	25
			5 (total)	144 (total)

Tab. 6: Non threatened endemic Malagasy amphibian species (IUCN, 2021) that were successfully bred in zoos within the last 12 months (according to ZIMS).

	IUCN status	Region	Institutions (7 in total)	Individuals bred (769 in total)
Dyscophus antongilii	LC	Russia	Moscow Zoo	3
		Switzerland	Zurich Zoo	1
			2 (total)	4 (total)
D. guineti	LC	France	Parc Zoologique de Paris	500
			1 (total)	500 (total)
Heterixalus alboguttatus	LC	UK	Drayton Manor Park Zoo	138
			1 (total)	138 (total)
H. madagascariensis	LC	Russia	Moscow Zoo	3
			1 (total)	3 (total)
Mantella baroni	LC	France	Parc Zoologique de Paris	100
			1 (total)	100 (total)
M. betsileo	LC	USA	Bronx Zoo	2
			1 (total)	2 (total)
M. laevigata	LC	USA	Detroit Zoo	20
			Omaha's Henry Doorly Zoo	2
			2 (total)	22 (total)

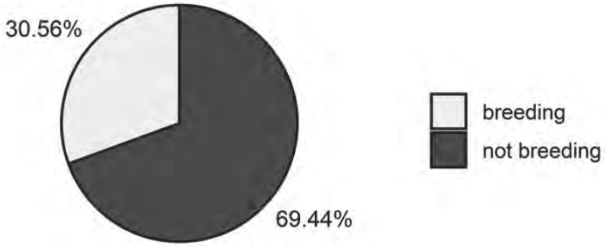

Fig. 10: Percentage of endemic Malagasy amphibian species globally held in zoos for which reproduction was documented in the last 12 months (according to ZIMS).

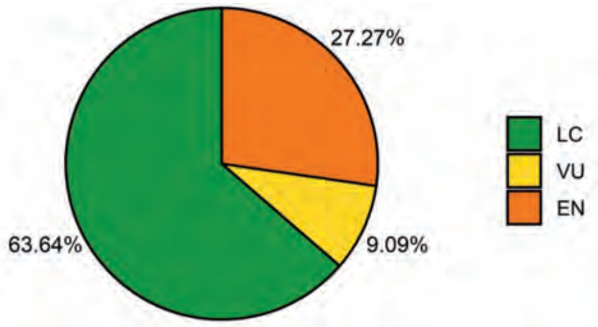

Fig. 11: Threat status of endemic Malagasy amphibian species (IUCN, 2021) bred in captivity in the last 12 months (according to ZIMS).

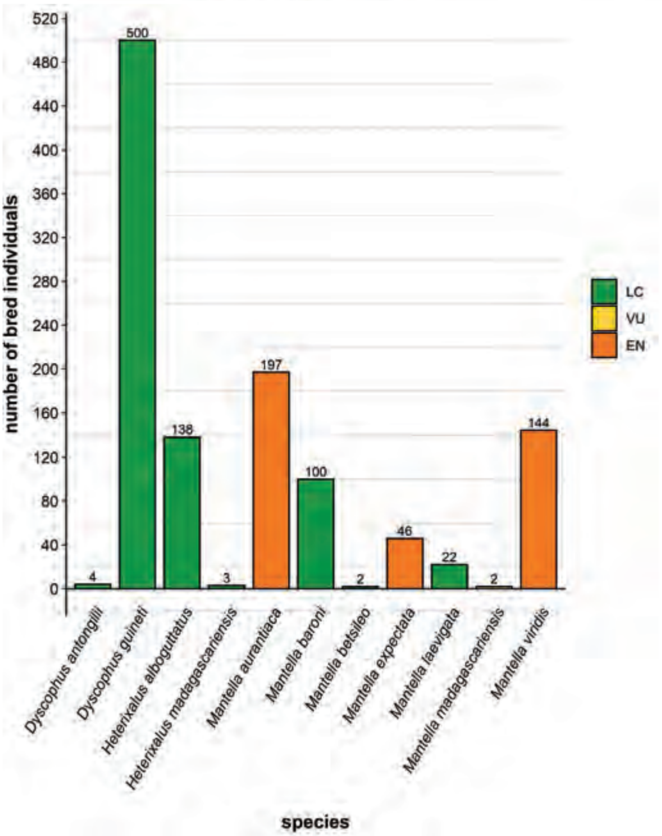

Fig. 12: Threat status and number of bred individuals of kept endemic Malagasy amphibian species in the last 12 months (IUCN, 2021).

Threatened endemic Malagasy amphibian species that are not yet held in captivity

There are currently 135 threatened Malagasy amphibian species that are not yet kept in zoos (Tabs. 7–8). 39 of these are Vulnerable, 76 are Endangered and 20 are Critically Endangered (IUCN, 2021). From the subfamily Boophinae 35 threatened species are not yet kept, two species of Laliostominae, 49 of Mantellinae and 49 of Cophylinae.

Tab. 7: Threatened Malagasy amphibian species of the family Mantellidae not yet kept in zoos according to ZIMS / ZTL (threat status in brackets).

Boophinae	*Boophis* (*B.*) *solomaso* (EN)	*Gephyromantis* (*P.*) *kintana* (EN)
Boophis (*B.*) *andohahela* (VU)	*B.* (*B.*) *spinophis* (VU)	*G.* (*P.*) *corvus* (EN)
B. (*B.*) *andrangoloaka* (EN)	*B.* (*B.*) *tsilomaro* (CR)	*G.* (*Vatomantis*) *rivicola* (VU)
B. (*B.*) *andreonei* (VU)	*B.* (*B.*) *ulftunni* (VU)	*G.* (*V.*) *silvanus* (VU)
B. (*B.*) *anjanaharibeensis* (EN)	*B.* (*B.*) *vittatus* (VU)	*G.* (*V.*) *webbi* (EN)
B. (*B.*) *ankarafensis* (CR)	*B.* (*B.*) *williamsi* (CR)	*Guibemantis* (*G.*) *diphonus* (CR)
B. (*B.*) *arcanus* (EN)	**Laliostominae**	*G.* (*G.*) *kathrinae* (VU)
B. (*B.*) *baetkei* (CR)	*Aglyptodactylus australis* (EN)	*G.* (*G.*) *annulatus* (EN)
B. (*B.*) *blommersae* (VU)	*A. laticeps* (VU)	*G.* (*P.*) *punctatus* (CR)
B. (*B.*) *boehmei* (EN)	**Mantellinae**	*Guibemantis* (*P.*) *tasifotsy* (VU)
B. (*B.*) *boppa* (EN)	*Boehmantis microtympanum* (VU)	*G.* (*P.*) *wattersoni* (EN)
B. (*B.*) *brachychir* (VU)	*Gephyromantis* (*Asperomantis*) *ambohitra* (VU)	*Mantella cowanii* (EN)
B. (*B.*) *englaenderi* (VU)	*G. (Asperomantis) spinifer* (VU)	*M. haraldmeieri* (EN)
B. (*B.*) *fayi* (VU)	*G.* (*A.*) *tahotra* (VU)	*M. manery* (VU)
B. (*B.*) *feonnyala* (EN)	*G.* (*Duboimantis*) *cornutus* (VU)	*Mantidactylus* (*Brygoomantis*) *bourgati* (EN)
B. (*B.*) *haematopus* (EN)	*G.* (*D.*) *salegy* (VU)	*M.* (*B.*) *madecassus* (EN)
B. (*B.*) *haingana* (EN)	*G.* (*D.*) *schilfi* (VU)	*M.* (*B.*) *pauliani* (CR)
B. (*B.*) *jaegeri* (EN)	*G.* (*D.*) *tandroka* (VU)	*M.* (*B.*) *tricinctus* (VU)
B. (*B.*) *laurenti* (EN)	*G.* (*D.*) *zavona* (EN)	*M.* (*Chonomantis*) *albofrenatus* (EN)
B. (*B.*) *liami* (CR)	*G.* (*G.*) *eiselti* (EN)	*M.* (*C.*) *delormei* (EN)
B. (*B.*) *majori* (VU)	*G.* (*G.*) *enki* (VU)	*M.* (*C.*) *paidroa* (EN)
B. (*B.*) *miadana* (EN)	*G.* (*G.*) *hintelmannae* (EN)	*M.* (*C.*) *zolitschka* (CR)
B. (*B.*) *miniatus* (VU)	*G.* (*Gephyromantis*) *mafy* (CR)	*Spinomantis brunae* (EN)
B. (*B.*) *narinsi* (EN)	*G.* (*G.*) *runewsweeki* (VU)	*S. guibei* (VU)
B. (*B.*) *piperatus* (EN)	*G.* (*G.*) *thelenae* (EN)	*S. massi* (VU)
B. (*B.*) *popi* (VU)	*G.* (*L. incert.*) *klemmeri* (EN)	*S. microtis* (EN)
B. (*B.*) *rhodoscelis* (EN)	*G.* (*L.*) *horridus* (VU)	*S. nussbaumi* (CR)
B. (*B.*) *sambirano* (EN)	*G.* (*L.*) *ranjomavo* (EN)	*S. tavaratra* (VU)
B. (*B.*) *sandrae* (EN)	*G.* (*Laurentomantis*) *striatus* (VU)	*Tsingymantis antitra* (EN)
B. (*B.*) *schuboeae* (EN)	*G.* (*Phylacomantis*) *atsingy* (EN)	

Fig. 13: Threatened endemic Malagasy amphibians (Boophinae) not yet held in zoos: *Boophis fayi* (VU, upper left), *B. sandrae* (EN, upper right), *B. solomaso* (EN, lower left), *B. williamsi* (CR, lower right, photos: A. Crottini).

Fig. 14: Threatened endemic Malagasy amphibians (Mantellinae) not yet held in zoos: *Gephyromantis kintana* (EN, upper left, photo: A. Crottini), *Mantella cowanii* (EN, upper right, photo: G. Garcia), *Mantidactylus pauliani* (CR, lower left, photo: A. Crottini), *Tsingymantis antitra* (EN, lower right, photo: F. Glaw).

Tab. 8: Threatened Malagasy amphibian species of the family Microhylidae not yet kept in zoos according to ZIMS (threat status in brackets).

Cophylinae	*Plethodontohyla brevipes* (VU)
Anilany helenae (CR)	*P. fonetana* (EN)
Anodonthyla emilei (EN)	*P. guentheri* (EN)
A. hutchisoni (EN)	*Rhombophryne botabota* (EN)
A. jeanbai (EN)	*R. guentherpetersi* (EN)
A. montana (VU)	*R. longicrus* (EN)
A. moramora (EN)	*R. mangabensis* (VU)
A. nigrigularis (EN)	*R. matavy* (CR)
A. rouxae (EN)	*R. minuta* (EN)
A. theoi (CR)	*R. ornata* (EN)
A. vallani (CR)	*R. savaka* (EN)
Cophyla berara (EN)	*R. serratopalpebrosa* (EN)
C. maharipeo (CR)	*R. tany* (EN)
C. noromalalae (EN)	*R. testudo* (EN)
C. occultans (VU)	*R. vaventy* (EN)
C. puellarum (CR)	*Stumpffia analamaina* (CR)
Madecassophryne truebae (EN)	*S. be* (EN)
Platypelis alticola (EN)	*S. hara* (CR)
P. karenae (CR)	*S. kibomena* (EN)
P. mavomavo (EN)	*S. madagascariensis* (EN)
P. milloti (EN)	*S. miery* (EN)
P. olgae (EN)	*S. psologlossa* (EN)
P. ravus (EN)	*S. pygmaea* (EN)
P. tetra (EN)	*S. roseifemoralis* (EN)
P. tsaratananaensis (EN)	*S. staffordi* (VU)

Fig. 15: Threatened endemic Malagasy amphibians (Microhylidae) not yet held in zoos: *Cophyla puellarum* (CR, upper left), *Platypelis karenae* (CR, upper right, photos: A. Crottini), *Plethodontohyla fonetana* (EN, lower left), *Rhombophryne matavy* (CR, lower right, photos: F. Glaw).

Species diversity and threat evaluation of Malagasy reptiles

Currently, 437 different reptile species are reported to occur in Madagascar (Uetz et al., 2021). 420 of these 437 reptile species are endemic to Madagascar. In our analyses we will focus on the 420 species of reptiles endemic to Madagascar. The other reptile species are either introduced or occur naturally in other regions next to Madagascar. The most diverse family is Gekkonidae with a total number of 126 species. Of the endemic reptile species, 133 (32%) are threatened: 23 Critically Endangered (of which one species is possibly extinct: *Pseudoxyrhopus ankafinaensis*), 53 Endangered, and 57 Vulnerable (IUCN, 2021). Of the remaining 287 endemic reptile species, 201 species (48%) are evaluated as not threatened: 45 species as Near Threatened and 156 species Least Concern. Another 86 species (20%) are either Data Deficient (n = 40) or Not Evaluated (n = 46) (IUCN, 2021) (Fig. 16).

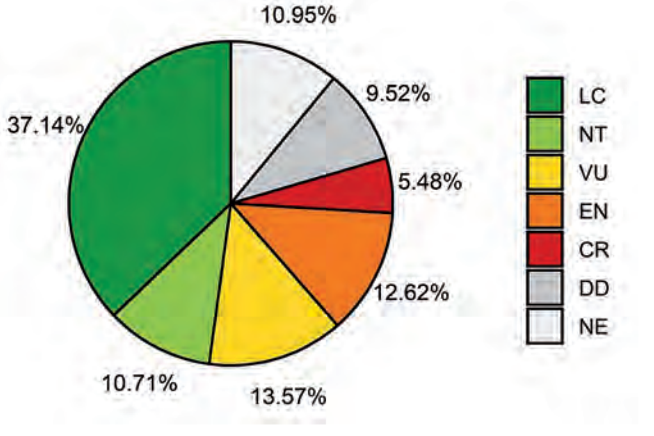

Fig. 16: Threat status of endemic Malagasy reptile species (n = 420) according to IUCN (2021).

Endemic Malagasy reptile species globally held in zoos according to ZIMS

Of the 420 endemic Malagasy reptile species, 87 species (21%) are kept globally in zoos (Tab. 9). Only 24 of these species (28%) are classified as threatened representing only a small fraction of all 133 endemic Malagasy reptile species (18%) that are threatened. Of the 24 threatened species kept seven are Critically Endangered, five are Endangered and 12 are listed as Vulnerable (IUCN, 2021). With 60 species, most of the species held are not threatened (69%). Seven of these species are listed as Near Threatened and the majority (53 species / 61%) as Least Concern. *Phelsuma hoeschi* is listed as Data Deficient and *Paroedura guibei* as well as *Sanzinia volontany* are not yet evaluated.

The family Testudinidae represents most individuals held. With 1441 individuals held in zoos globally the species *Astrochelys radiata* is the most frequently held species according to ZIMS. *A. radiata* is followed by *A. yniphora* with 760 animals of which 707 individuals are kept at Ampijoroa Chelonian Captive Breeding Centre in Madagascar. With 46 species the Gekkonidae is the most commonly held family of Malagasy reptiles. Chameleons (Chamaeleonidae) are represented in zoos by the two subfamilies Brookesiinae (1 species) and Chamaeleoninae (8 species). Other Malagasy reptile families are represented in zoos by the following endemic taxa: Gerrhosauridae (9 species), Opluridae (6 species), Pseudoxyrophiidae (7 species) and Sanziniidae and Testudinidae, each with four species. The family Podocnemididae is represented with the only species that occurs in Madagascar. Malagasy species of the following families are not globally kept in zoos: Psammophiidae, Typhlopidae and Xenotyphlopidae.

Tab. 9: Endemic Malagasy reptile species held in zoos globally according to ZIMS, with number of institutions and total number of individuals kept; * = threatened species according to IUCN (2021).

Species	Zoos	Individuals	Species	Zoos	Individuals
Chamaeleonidae			*U. fimbriatus*	17	132
Brookesiinae			*U. giganteus**	4	34
Brookesia stumpffi	1	1	*U. henkeli**	66	443
Chamaeleoninae			*U. lineatus*	7	33
Calumma brevicorne	1	2	*U. phantasticus*	8	56
*C. globifer**	1	2	*U. sikorae*	15	62
C. parsonii	7	18	**Gerrhosauridae**		
Furcifer lateralis	4	9	*Tracheloptychus madagascariensis*	2	6
*F. minor**	2	5	*T. petersi**	2	6
F. oustaleti	2	5	*Zonosaurus haraldmeieri*	1	1
F. pardalis	92	335	*Z. karsteni*	4	13
F. verrucosus	1	1	*Z. laticaudatus*	6	15
Gekkonidae			*Z. maximus**	5	13
Blaesodactylus antongilensis	2	29	*Z. ornatus*	4	13
B. sakalava	1	2	*Z. quadrilineatus**	10	30
Ebenavia inunguis	1	4	*Z. trilineatus*	1	1
Geckolepis maculata	2	3	**Opluridae**		
G. typica	1	1	*Chalarodon madagascariensis*	4	8
Lygodactylus guibei	1	1	*Oplurus cyclurus*	6	15
L. pictus	1	2	*O. fierinensis*	1	2
*Matoatoa brevipes**	1	2	*O. grandidieri*	1	4
*Paroedura androyensis**	1	2	*O. quadrimaculatus*	1	5
P. bastardi	1	1	*O. saxicola*	1	1
P. guibei	1	1	**Podocnemididae**		
P. ibityensis	2	14	*Erymnochelys madagascariensis**	12	42
*P. lohatsara**	1	3	**Pseudoxyrophiidae**		
*P. masobe**	1	1	*Langaha madagascariensis*	7	14
P. oviceps	1	2	*Leioheterodon geayi*	3	11
P. picta	10	20	*L. madagascariensis*	28	64
P. stumpffi	1	8	*L. modestus*	2	5
*P. vazimba**	1	5	*Madagascarophis colubrinus*	5	12
*Phelsuma breviceps**	3	9	*M. meridionalis*	2	5
P. dorsivittata	1	1	*Pseudoxyrhopus quinquelineatus*	1	1
P. dubia	1	1	**Sanziniidae**		
P. grandis	112	659	*Acrantophis dumerili*	112	363
*P. hielscheri**	1	1	*A. madagascariensis*	46	123
P. hoeschi	1	2	*Sanzinia madagascariensis*	75	208
*P. klemmeri**	43	272	*S. volontany*	4	6
P. kochi	11	39	**Scincidae**		
P. laticauda	11	33	**Mabuyinae**		
P. lineata	8	17	*Trachylepis elegans*	1	10
P. madagascariensis	50	277	**Scincinae**		
P. mutabilis	1	3	*Amphiglossus astrolabi*	1	2
P. parva	2	11	*A. reticulatus*	2	3
*P. pronki**	2	4	*Grandidierina fierinensis*	1	2
P. quadriocellata	7	30	**Testudinidae**		
*P. seippi**	1	8	*Astrochelys radiata**	173	1441
*P. standingi**	83	221	*A. yniphora**	13	760
Uroplatus alluaudi	2	71	*Pyxis arachnoides**	16	70
*U. ebenaui**	3	71	*P. planicauda**	21	135

Fig. 17: Threatened endemic Malagasy reptiles held in zoos: *Paroedura masobe* (EN, left), *Erymnochelys madagascariensis* (CR, right, photos: A. Crottini).

Endemic Malagasy reptile species held in European institutions according to ZTL

The ZTL analysis revealed 82 endemic Malagasy reptile species held in European zoos. 20 of the species listed in ZTL are threatened (in alphabetical order and number of institutions in brackets): *Astrochelys radiata* (91), *A. yniphora* (6), *Blaesodactylus boivini* (2), *Calumma globifer* (1), *Erymnochelys madagascariensis* (5), *Furcifer minor* (1), *F. petteri* (1), *Paroedura lohatsara* (1), *Phelsuma breviceps* (2), *P. flavigularis* (2), *P. hielscheri* (1), *P. klemmeri* (37), *P. pronki* (1), *P. standingi* (53), *Pyxis planicauda* (2), *Tracheloptychus petersi* (2), *Uroplatus ebenaui* (1), *U. henkeli* (24), *Zonosaurus maximus* (7) and *Z. quadrilineatus* (8). Six of these species are listed as Critically Endangered, four as Endangered and 10 as Vulnerable (Figs. 18–19; Tab. 10)

10 of the 82 species were not included in ZIMS (in alphabetical order and number of institutions in brackets): *Blaesodactylus boivini* (2), *Brachyseps macrocercus* (1), *B. punctatus* (1), *Brookesia antakarana* (1), *B. thieli* (1), *Calumma boettgeri* (1), *Furcifer petteri* (1), *F. willsii* (1), *Geckolepis polylepis* (1), *Phelsuma flavigularis* (2).

Three of these 10 species not included in ZIMS are threatened: *Blaesodactylus boivini* (VU), *Furcifer petteri* (VU) and *Phelsuma flavigularis* (EN).

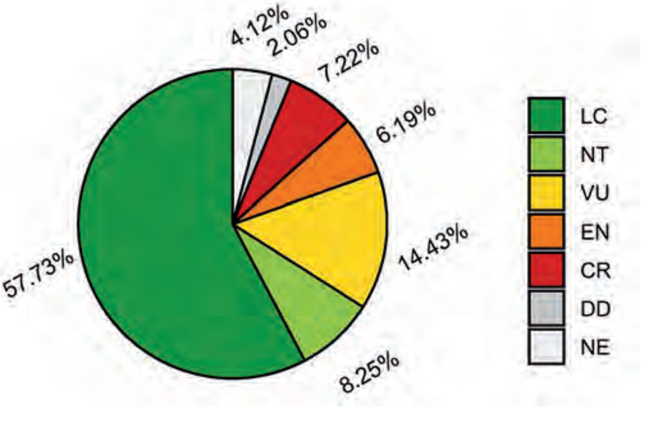

Fig. 18: IUCN threat status (2021) of endemic Malagasy reptile species kept in zoos (n = 97, according to ZIMS and ZTL analyses).

Tab. 10: Threatened endemic Malagasy reptiles (IUCN, 2021) held in zoos according to ZIMS (globally) and ZTL (only Europe, and only institutions not contained in ZIMS). Institutions are listed only if less than 10.

Family (subfamily) / species	Threat status	Institutions according to ZIMS	Institutions according to ZTL (not contained in ZIMS)
Testudinidae			
Astrochelys radiata	CR	173 institutions in 6 regions	27 institutions
A. yniphora	CR	13 institutions in 4 regions	- Pairi Daiza (Belgium) - Berlin Tierpark Friedrichsfelde (Germany)
Pyxis arachnoides	CR	16 institutions in 4 regions	
P. planicauda	CR	21 institutions in 3 regions	
Podocnemididae			
Erymnochelys madagascariensis	CR	12 institutions in 2 regions	- Graz Turtle Island (Austria)
Chamaeleonidae (Chamaeleoninae)			
Calumma globifer	EN	- Moscow Zoo (Russia)	
Furcifer minor	EN	- Leningrad Zoo (Russia) - Knoxville Zoo (USA)	
F. petteri	VU		- Moscow Zoo (Russia)
Gekkonidae			
Blaesodactylus boivini	VU		- Plzen Zoo (Czech Republic) - Jonsdorf Schmetterlingshaus (Germany)
Matoatoa brevipes	VU	- Plzen Zoo (Czech Republic)	
Paroedura androyensis	VU	- Plzen Zoo (Czech Republic)	
P. lohatsara	CR	- Cologne Zoo (Germany)	
P. masobe	EN	- Plzen Zoo (Czech Republic)	
P. vazimba	VU	- Plzen Zoo (Czech Republic)	
Phelsuma breviceps	VU	- Allwetterzoo Münster (Germany) - Plzen Zoo (Czech Republic) - Wroclaw Zoo (Poland)	
P. flavigularis	VU		- Plzen Zoo (Czech Republic) - Zájezd Zoopark
P. hielscheri	EN	- Plzen Zoo (Czech Republic)	
P. klemmeri	CR	43 institutions in 2 regions	17 institutions
P. pronki	EN	- Chester Zoo (UK) - Tiergarten der Stadt Nürnberg (Germany)	
P. seippi	EN	- Plzen Zoo (Czech Republic)	
P. standingi	VU	83 institutions in 2 regions	32 institutions
Uroplatus ebenaui	VU	- Moscow Zoo (Russia) - Riverbanks Zoo (USA) - Houston Zoo, Inc. (USA)	
U. giganteus	VU	- Disney's Animal Kingdom (USA) - Jacksonville Zoo (USA) - Omaha's Henry Doorly Zoo (USA) - Riverbanks Zoo (USA)	
U. henkeli	VU	66 institutions in 3 regions	- Bremen botanika - Tierpark Senftenberg(Germany) - Barcelona Zoo (Spain) - Madrid Safari Park Aldea del Fresno (Spain) - Helsingborg Tropicariet (Finland) - Tilgate Nature Tropikariet (Sweden)
Gerrhosauridae			
Tracheloptychus petersi	VU	- Drayton Manor Park Zoo (UK) - Plzen Zoo (Czech Republic)	
Zonosaurus maximus	VU	- Chester Zoo (UK) - Plzen Zoo (Czech Republic) - Steinhart Aquarium (USA) - Cango Wildlife Ranch (South Africa) - Zoo and Aqua-Terrarium Nonprofit Company (Hungary)	- Pairi Daiza (Belgium) - Tropicarium Park (Italy) - Zoo da Maia (Portugal) - Rio Safari Elche (Spain)
Z. quadrilineatus	VU	10 institutions in 3 regions	- Madrid Safari Park Aldea del Fresno (Spain) - RepZOOtic Animal Centre (Hungary)

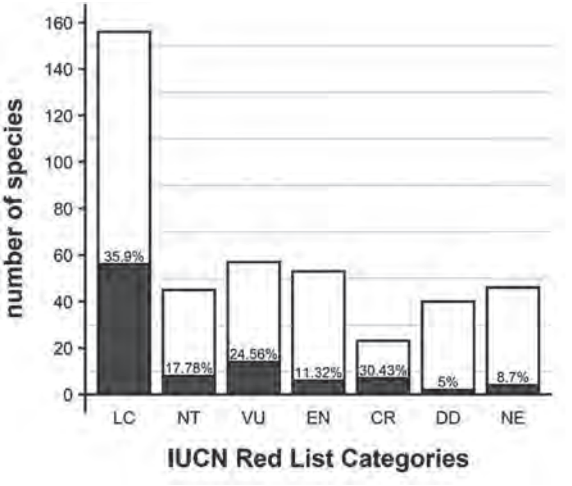

Fig. 19: Endemic Malagasy reptile species (white) and percentage of endemic Malagasy reptile species globally kept in zoos (dark) organised by threat status (according to ZIMS and ZTL analyses).

Endemic Malagasy reptile species held in zoos by continents

Endemic Malagasy reptile species are recorded from institutions in Africa, Asia, Europe, North America, South America and Australia/Oceania (Figs 20 and 22). With 83 endemic spe-

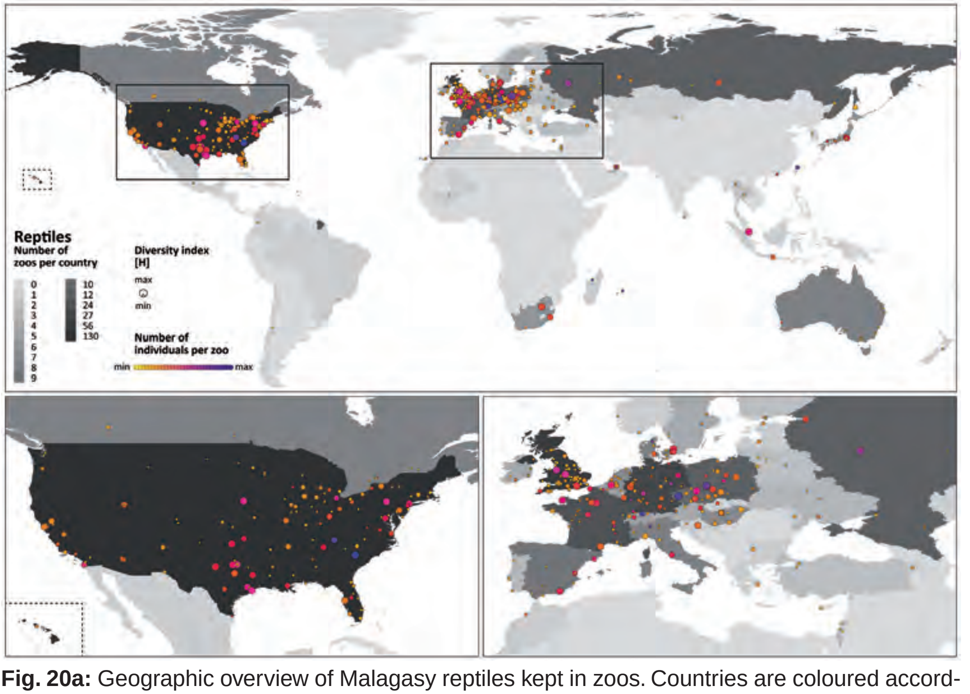

Fig. 20a: Geographic overview of Malagasy reptiles kept in zoos. Countries are coloured according to the number of zoos keeping specimens. Coloured dots represent single zoos, their colours refer to the number of individuals and their sizes code for H = Shannon Weaver Index. Inserts highlight the most relevant areas, i.e. North America and Europe with the highest density of zoos.

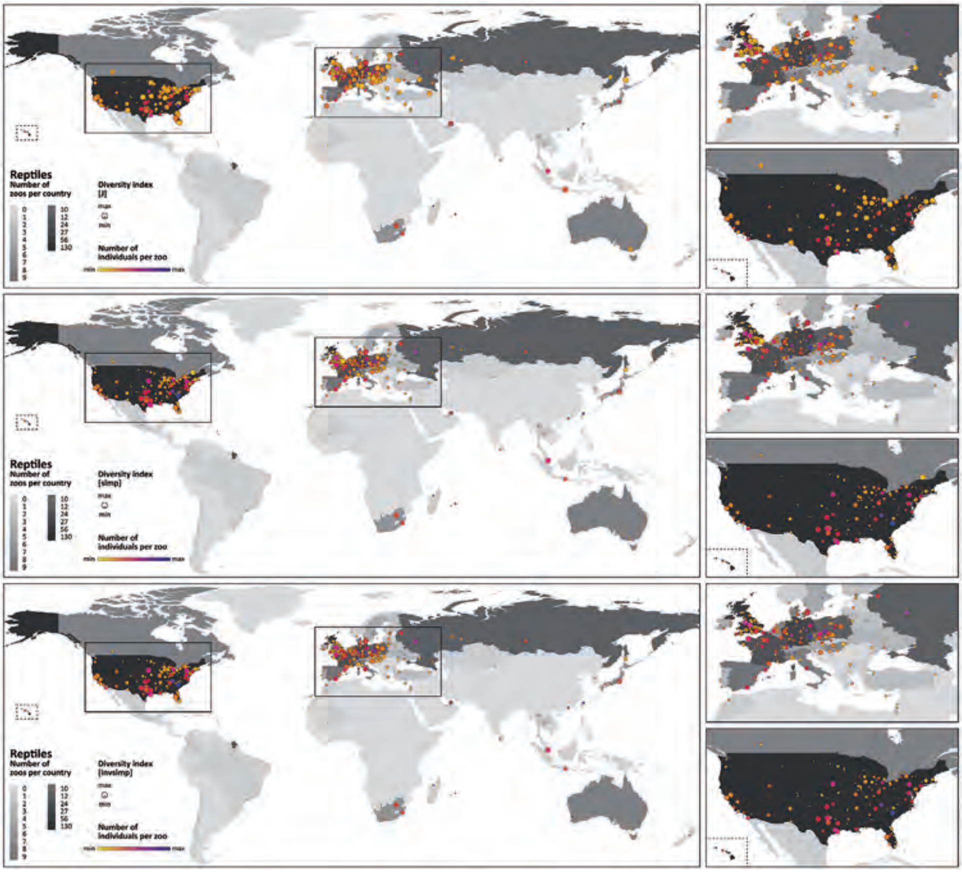

Fig. 20b: Geographic overview of reptiles from Madagascar kept in zoos. Countries are coloured according to the number of zoos keeping specimens. Coloured dots represent single zoos, their colours refer to the number of individuals, and their sizes code for the respective diversity index: J = Pielou's Evenness, simp = Simpson Index, and invsimp = inverse Simpson Index. Inserts highlight the most relevant areas, i.e. North America and Europe with the highest density of zoos.

cies kept according to ZIMS, European zoos are leading, followed by North American zoos, where 40 species are held. In Asian zoos 18 endemic Malagasy reptile species are held and in Africa 15. Australia and South America keep three endemic species each (Fig. 20). Most zoos keep only a limited number of individuals and cover a rather low diversity (Fig. 21). However, some institutions are more specialised on Malagasy reptiles.

In Europe in total 3033 individuals of endemic Malagasy reptiles are held in 230 institutions according to ZIMS. In North America, 2013 individuals are kept in 146 zoos. In Asian zoos 403 individuals are held in 27 institutions and in South America only three individuals are held in three zoos. In Africa and Oceania/Australia nine institutions keep endemic Malagasy reptile species, with 871 individuals being held in Africa and 53 individuals in institutions in Oceania/Australia.

Most of the kept species per continental region are listed as Least Concern. Of the 53 kept species listed as Least Concern most are kept in Europe (n = 50), followed by North America with 25 species. In Africa and Asia 11 species listed as Least Concern are held. South America

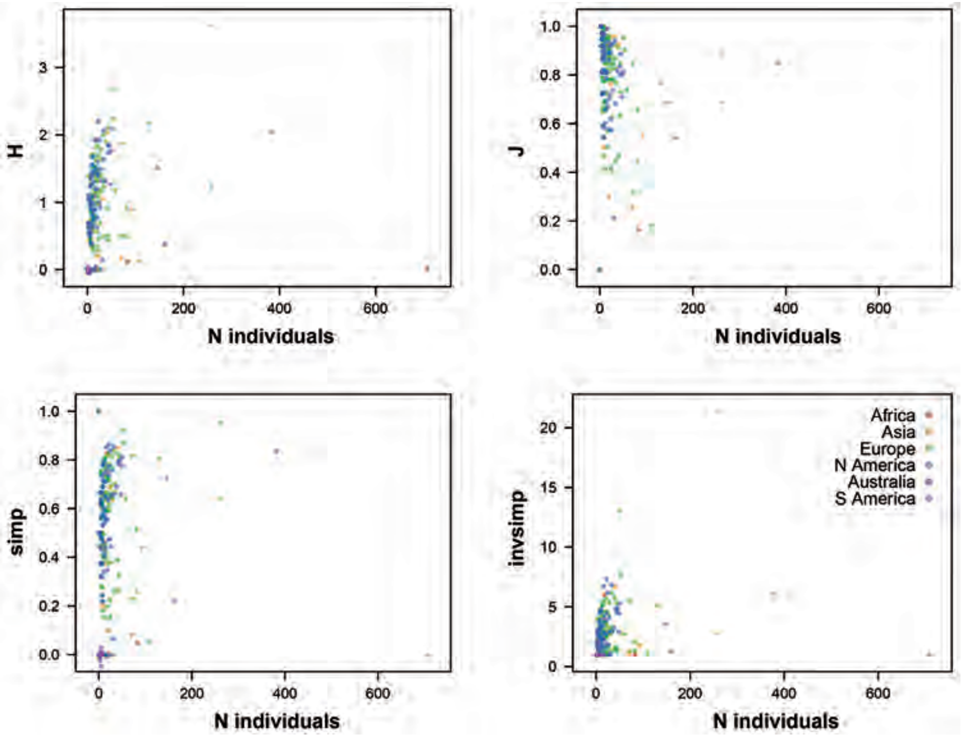

Fig. 21: Diversity of reptiles versus number of individuals per zoo in each continent. H = Shannon Weaver Index, J = Pielou's evenness, simp = Simpson Index, invsimp = Inverse Simpson Index.

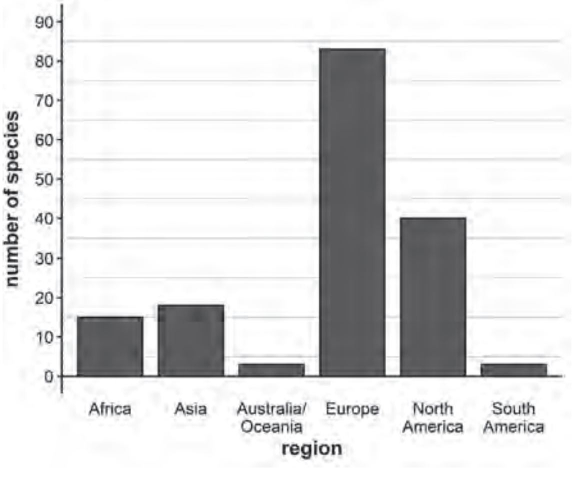

Fig. 22: Endemic Malagasy reptile species held in zoos by continental regions.

and Australia/Oceania each keep only three species of which two species are listed as Least Concern and the other species is listed as Critically Endangered (Fig. 23). Most threatened species are kept in Europe (n = 23). Eleven of these species are listed as Vulnerable, five as Endangered and seven as Critically Endangered, which amounts to 27% of all species kept in this region. With 13 threatened species (6 VU, 2 EN, 5 CR) North America has the highest percentage of threatened species of Malagasy reptiles in captivity (Tab. 11).

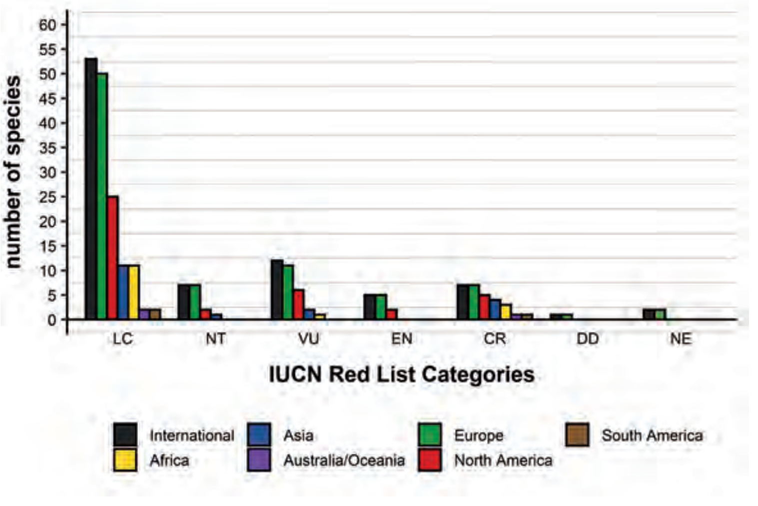

Fig. 23: Threat status of kept endemic Malagasy reptile species sorted by continental regions (IUCN, 2021); international refers to the number of species globally held.

Tab. 11: Endemic Malagasy reptile species held in zoos worldwide except Europe (according to ZIMS).

Region	Country	Species held (threatened)	Individuals	Institutions	Zoos with most species held (species numbers held in brackets)
America	Canada	4 (1)	24	7	Calgary Zoo (3)
	USA	40 (13)	1989	139	Omaha's Henry Doorly Zoo (13)
South America	Brazil	1 (1)	1	1	Parque Zoologico de Sao Paulo (1)
	Colombia	1 (0)	1	1	Bioparque Ukumarí (1)
	Chile	1 (0)	1	1	Parque Zoológico Buin Zoo (1)
Asia	Armenia	2 (0)	5	1	Yerevan Zoo (2)
	Cyprus	2 (0)	4	1	Paphos Zoo (2)
	Hongkong	2 (2)	26	2	Kadoorie Farm & Botanic Garden (2)
	Indonesia	3 (0)	15	1	Batu Secret Zoo (3)
	Israel	3 (1)	3	3	Hai Park Kiriat Motzkin (1) The Tisch Family Zoological Gardens (1) Zoological Centre Ramat Gan (1)
	Japan	12 (4)	79	7	Ueno Zoological Gardens (7)
	Kazakhstan	1 (0)	4	1	Almaty State Zoo of Kazakhstan (1)
	Singapore	9 (4)	40	1	Singapore Zoo (9)
	South Korea	1 (1)	1	1	Seoul Zoo (1)
	Sri Lanka	1 (0)	9	1	Department of National Zoological Gardens (1)
	Taiwan	5 (3)	92	1	Taipei Zoo (5)
	Thailand	1 (1)	5	2	Chiangmai Zoological Garden (1) & Nakhon Ratchasema Zoological Park (1)
	Turkey	2 (0)	7	2	Faruk Yalcin Zoo (2)
	United Arab. Emirates	6 (2)	113	4	The Green Planet Dubai (3)
Africa	South Africa	13 (2)	70	6	Montecasino Bird Gardens (8)
	Madagascar	1 (1)	707	1	Ampijoroa Chelonian Captive Breeding Centre (1)
	Mauritius	2 (2)	83	1	Casela World of Adventures (2)
	Morocco	2 (1)	11	1	Jardin Zoologique National (2)
Oceania	Australia	3 (1)	51	8	Melbourne Zoo (2)
	New Zealand	1 (0)	2	1	Wellington Zoo (1)

Endemic Malagasy reptile species held in European zoos

According to ZIMS, zoos in 31 European countries keep endemic Malagasy reptiles (Tab. 12). Most species (63) are kept in the Czech Republic (59 of these in the Plzen Zoo), followed by the UK (35 species) and Germany with 22 species. Of the 63 species kept in the Czech Republic, 14 are threatened, making Czech Republic the country with most threatened endemic Malagasy reptile species held. Germany and the UK keep 11 threatened species each, followed by France and Russia, where six threatened species are kept in each country. Six of the European countries where endemic Malagasy reptile species are kept keep no threatened species.

Most individuals are kept in institutions in Germany (487), followed by the Czech Republic with 365 and the UK with 361 individuals. Most institutions that keep endemic Malagasy reptile species are in the UK (56), followed by Germany (29) and France (25).

Tab. 12: Endemic Malagasy reptile species in European zoos (according to ZIMS).

Country	Species held (threatened)	Individuals	Institutions	Zoos with most species held (species numbers held in brackets)
Austria	8 (2)	35	4	Schönbrunner Tiergarten GmbH (4)
Belarus	3 (0)	5	2	Grodznenski Dzyarzhauny Zaalagichny Park (2)
Belgium	13 (4)	85	5	Antwerp Zoo (10)
Bulgaria	3 (1)	6	1	Sofia Zoological Gardens (3)
Croatia	5 (3)	12	1	Zagreb Zoo (5)
Czech Republic	63 (14)	365	12	Plzen Zoo (59)
Denmark	6 (2)	125	8	Copenhagen Zoo (4) Terrarium Vissenbjerg (4)
Estonia	2 (1)	6	1	Tallinn Zoo (2)
Finland	3 (0)	9	2	Helsinki Zoo (3)
France	14 (6)	332	25	Parc Zoologique de Paris (7)
Germany	22 (11)	487	29	Cologne Zoo (7)
Greece	3 (1)	9	1	Attica Zoological Park S.A. (3)
Hungary	11 (3)	37	7	Budapest Zoo (5)
Ireland	3 (0)	14	4	Fota Wildlife Park (2)
Italy	9 (2)	146	7	Rome Zoo (6)
Latvia	3 (2)	9	1	Riga Zoo (3)
Lithuania	2 (0)	4	2	Lietuvos Zoologijos Sodas & VSI Zoopark.lt (1)
Luxembourg	4 (1)	15	1	Parc Merveilleux (4)
Moldova	2 (0)	4	1	Kishinev Zoopark (2)
Netherlands	8 (4)	31	7	Dierenpark Amersfoort (2) ARTIS Amsterdam Royal Zoo (2) Rotterdam Zoo (2) Stichting Reptielenhuis De Oliemeulen (2)
Norway	3 (1)	5	2	Kristiansand Dyrepark ASA (2)
Poland	19 (5)	272	12	Wroclaw Zoo (17)
Portugal	4 (1)	9	3	Jardim Zoologico / Lisbon Zoo (2)
Russia	21 (6)	129	10	Moscow Zoo (9)
Slovakia	4 (1)	17	1	Zoologicka zahrada Bojnice (4)
Slovenia	1 (0)	5	1	Zivalski vrt Ljubljana (1)
Spain	11 (4)	118	11	Oasys Parque del Desierto de Tabernas (7)
Sweden	8 (3)	59	5	Helsingborg Tropikariet (7)
Switzerland	11 (2)	307	5	Zurich Zoo (6)
UK	35 (11)	361	56	Drayton Manor Park Zoo (16)
Ukraine	4 (1)	15	3	Nikolaev Zoo of Nikolaev-City Council (3)

Reptilian reproduction success

Of the 87 endemic Malagasy reptile species globally kept in zoos according to ZIMS, 34 (39%) have successfully reproduced within the last 12 months (Fig. 26). With 23 out of 34 bred reptile species (68%) most species belong to the family Gekkonidae. 13 of the 34 bred reptile

Tab. 13: Threatened endemic Malagasy reptile species (IUCN, 2021) that successfully bred in zoos within the last 12 months (according to ZIMS).

Species	IUCN Status	Region	Institutions (45 in total)	Individuals bred (356 in total)
Testudinidae				
Astrochelys radiata	CR	South Africa	Cango Wildlife Ranch	2
		France	Le Jardin aux Oiseaux	14
			Lyon Zoo	3
			Mulhouse Zoo	2
			Touroparc	2
		Germany	Leipzig Zoo	7
			Zoologischer Garten Magdeburg	9
		UK	Chester Zoo	1
		Switzerland	Basel Zoo	1
		Spain	Oceanografic Valencia	1
		Czech Republic	Dvur Kralove Zoo	2
		USA	Fresno Chaffee Zoo	1
			Knoxville Zoological Gardens	1
			Bronx Zoo	2
			John L. Behler Chelonian Conservation Centre	5
			San Diego Zoo	8
			16 (total)	61 (total)
A. yniphora	CR	Madagascar	Ampijoroa Chelonian Captive Breeding Centre	80
			1 (total)	80 (total)
Pyxis arachnoides	CR	Germany	Hannover Zoo	2
			1 (total)	2 (total)
P. planicauda	CR	Germany	Tierpark Bern	2
		USA	Knoxville Zoo	6
			2 (total)	8 (total)
Gekkonidae				
Paroedura lohatsara	CR	Germany	Cologne Zoo	2
			1 (total)	2 (total)
Phelsuma breviceps	VU	Germany	Allwetterzoo Münster	4
			1 (total)	4 (total)
P. klemmeri	EN	France	Nausicaa	4
		Germany	Cologne Zoo	1
			Leipzig Zoo	1
			Wuppertal Zoo	1
		Poland	Lodz Zoo	25
		UK	Reaseheath College	1
		USA	Audubon Zoo	1
			Knoxville Zoo	33
			Smithsonian National Zoological Park	2
			Toledo Zoo	6
			10 (total)	75 (total)
P. pronki	CR	UK	Chester Zoo	2
			1 (total)	2 (total)
P. seippi	EN	Czech Republic	Plzen Zoo	8
			1 (total)	8 (total)
P. standingi	VU	Netherlands	Dierenpark Amersfoort	1
		Spain	Biotropica	5
		Germany	Zoo Landau	6
			Wuppertal Zoo	1
		Italy	Rome Zoo	1
		Estonia	Tallinn Zoo	1
			6 (total)	15 (total)
Uroplatus ebenaui	VU	Russia	Moscow Zoo	2
		USA	Riverbanks Zoo and Garden	21
			Houston Zoo, Inc.	9
			3 (total)	32 (total)
U. giganteus	VU	USA	Riverbanks Zoo and Garden	6
			1 (total)	6 (total)

Tab. 13: Continued.

U. henkeli	VU	UK	Chester Zoo	3
			Drayton Manor Park Zoo	4
			Tilgate Nature Centre	1
		USA	Clyde Peeling's Reptiland	1
			Cincinnati Zoo	2
			Riverbanks Zoo	11
			Henry Vilas Zoo	25
			Oklahoma City	1
			San Antonio Zoo	12
			Tulsa Zoo	1
			10 (total)	61 (total)

Fig. 24: Threatened endemic Malagasy reptiles bred in zoos in the last 12 months: *Paroedura lohatsara* (CR, top, adult, photo: F. Glaw; lower left, hatchling, photo: T. Ziegler), *Uroplatus giganteus* (VU, bottom right, photo: F. Glaw).

Fig. 25: Threatened endemic Malagasy reptiles, listed as Critically Endangered and bred in zoos in the last 12 months: *Astrochelys yniphora* (left), *Pyxis planicauda* (right, photos: A. Crottini).

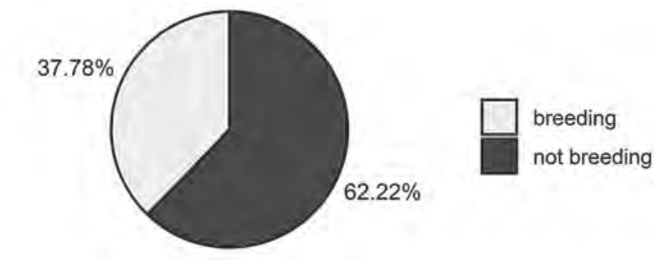

Fig. 26: Percentage of endemic Malagasy reptile species globally held in zoos for which reproduction was documented in the last 12 months (according to ZIMS).

Tab. 14: Non threatened endemic Malagasy reptile species (IUCN, 2021) that were successfully bred in zoos within the last 12 months (according to ZIMS).

Species	Threat status	Region	Institutions (27 in total)	Individuals bred (302 in total)
Chamaeleonidae				
Furcifer pardalis	LC	Singapore	Singapore Zoo	4
		Taiwan	Taipei Zoo	2
		Germany	Berlin Zoo	7
		Czech Republic	Zoo Dvur Kralove, a.s.	2
		Sweden	Malmö Aquarium and Tropicarium	3
		UK	Newquay Zoo	4
		Switzerland	Zurich Zoo	12
			7 (total)	34 (total)
Gekkonidae				
Geckolepis typica	LC	USA	Oklahoma Zoo	3
			1 (total)	3 (total)
Paroedura ibityensis	NT	Czech Republic	Plzen Zoo	9
			1 (total)	9 (total)
P. stumpffi	LC	Czech Republic	Plzen Zoo	3
			1 (total)	3 (total)
Phelsuma grandis	LC	Finland	Helsinki Zoo	1
		Singapore	Singapore Zoo	2
		Belgium	Zoo of Antwerp	1
		Netherlands	Aeres MBO Barneveld Animal Collection	2
		Denmark	Copenhagen Zoo	1
		Czech Republic	Zoo Dvur Kralove	2
		Germany	Thuringer Zoopark Erfurt	4

Tab. 14: Continued.

		Sweden	Malmö Aquarium and Tropicarium	2
			Helsingborg Tropikariet	1
		Slovenia	Zivalski vrt Ljubljana	3
		Poland	Wroclaw Zoo	5
		USA	Clyde Peeling's Reptiland	1
			Potter Park Zoological Gardens	3
			Tennessee Aquarium	3
			Toledo Zoo	5
			Virginia Zoological Park	7
			16 (total)	43 (total)
P. kochi	LC	Poland	Wroclaw Zoo	5
		USA	Metro Richmond Zoo	1
			2 (total)	6 (total)
P. laticauda	LC	Poland	Wroclaw Zoo	2
			1 (total)	2 (total)
P. lineata	LC	UK	Tilgate Nature Centre	2
		Poland	Wroclaw Zoo	3
		USA	Clyde Peeling's Reptiland	1
			3 (total)	6 (total)
P. madagascariensis	LC	United Arab. Emirates	Dubai Safari	3
		Ukraine	Nikolaev Zoo of Nikolaev-City Council	5
		Germany	Rostock Zoologischer Garten	7
			3 (total)	15 (total)
P. parva	LC	Germany	Wilhelma Zoo	14
			1 (total)	14 (total)
P. quadriocellata	LC	Poland	Wroclaw Zoo	6
			1 (total)	6 (total)
Uroplatus alluaudi	NT	Russia	Moscow Zoo	10
		USA	Riverbanks Zoo and Garden	25
			2 (total)	35 (total)
U. fimbriatus	LC	USA	Riverbanks Zoo	14
			Dallas Zoo	1
			2 (total)	15 (total)
U. phantasticus	LC	USA	Riverbanks Zoo	13
			Dallas Zoo	2
			Bronx Zoo	6
			Omaha's Henry Doorly Zoo	14
			4 (total)	35 (total)
U. sikorae	LC	Russia	Moscow Zoo	6
		USA	Riverbanks Zoo	12
			2 (total)	18 (total)
Gerrhosauridae				
Zonosaurus laticaudatus	LC	UK	Drayton Manor Park Zoo	7
			1 (total)	7 (total)
Opluridae				
Chalarodon madagascariensis	LC	Czech Republic	Plzen Zoo	1
			1 (total)	1 (total)
Scincidae				
Trachylepis elegans	LC	Czech Republic	Plzen Zoo	7
			1 (total)	7 (total)
Boidae				
Acrantophis dumerili	LC	UK	Dudley Zoo	2
		Germany	Tiergarten der Stadt Nürnberg	4
			2 (total)	6 (total)
A. madagascariensis	LC	USA	Bronx Zoo	1
			1 (total)	1 (total)
Sanzinia madagascariensis	LC	UK	Belfast Zoo	7
		France	Mulhouse Zoo	6
		Switzerland	Zurich Zoo	12
		USA	Metro Richmond Zoo	11
			4 (total)	36 (total)

species (38%) are threatened species (6 CR, 2 EN, 5 VU; Tab. 13–14; Figs. 27–28). Of the other 21 species (62%), two are listed as Near Threatened and 19 as Least Concern.

The highest breeding success, viz. with most bred individuals, within the last 12 months was that of *Astrochelys yniphora* with 80 bred individuals (all from Ampijoroa Chelonian Captive Breeding Centre in Madagascar). The Riverbanks Zoo and Garden (UK) was the institution with most species bred (7).

The two species listed as Least Concern, *Acrantophis madagascariensis* and *Chalarodon madagascariensis*, had the lowest breeding success with only one bred individual each.

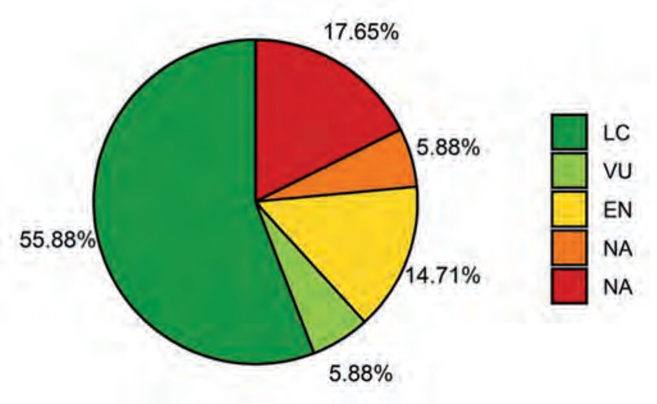

Fig. 27: Threat status of endemic Malagasy reptile species (IUCN, 2021) with documented captive breeding in the last 12 months (according to ZIMS).

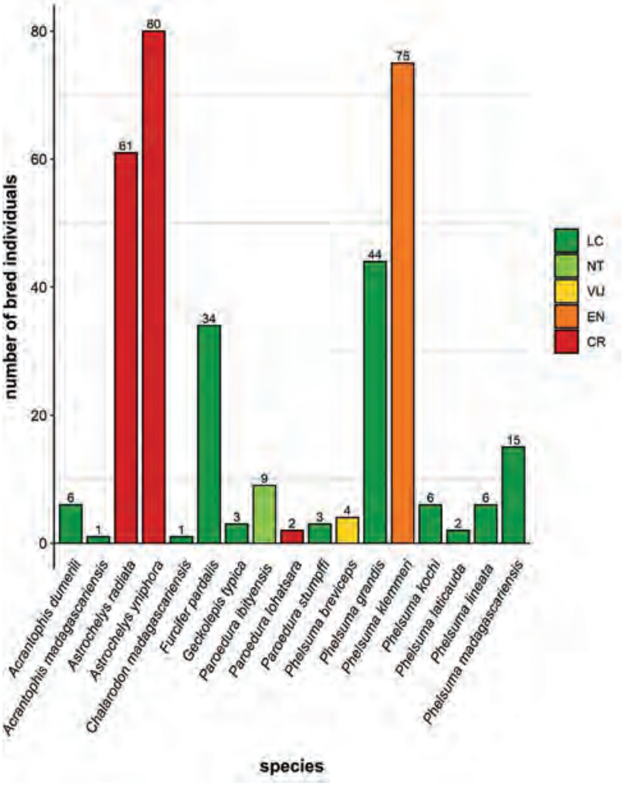

Fig. 28a: Threat status and number of bred individuals of kept endemic Malagasy reptile species (genus names A-*Phelsuma madagascariensis*) in the last 12 months (IUCN, 2021).

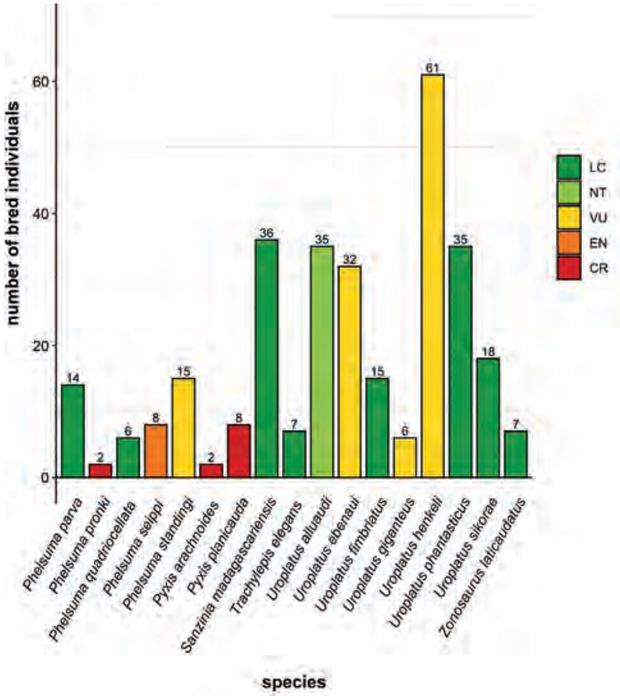

Fig. 28b: Threat status and number of bred individuals of kept endemic Malagasy reptile species (genus names *Phelsuma parva*-Z) in the last 12 months (IUCN, 2021).

Threatened endemic Malagasy reptile species that are not yet held in captivity

106 threatened endemic Malagasy reptile species are not kept in zoos currently (Tabs. 15–18). 43 of these species are Vulnerable, 47 are Endangered and 16 are Critically Endangered (IUCN, 2021). From the family Chamaelonidae, 41 threatened species are not yet kept, 18 belonging to the subfamily Brookesiinae and 23 to the subfamily Chamaeleoninae. 20 threatened species of the family Gekkonidae, three of the family Gerrhosauridae, 19 of the family Pseudoxyrophiidae, one of Xenotyphlopidae and 22 threatened species from the family Scincidae are also not yet globally kept in zoos.

Tab. 15: Threatened Malagasy chameleon species (Chamaeleonidae) not yet kept in zoos according to ZIMS and ZTL analyses (threat status in brackets).

Brookesiinae	*B. tuberculata* (VU)	*C. peyrierasi* (VU)
Brookesia bekolosy (EN)	*B. vadoni* (VU)	*C. tarzan* (CR)
B. bonsi (CR)	*B. valerieae* (EN)	*C. tsaratananense* (VU)
B. decaryi (EN)	*Palleon nasus* (VU)	*C. tsycorne* (VU)
B. dentata (EN)	**Chamaeleoninae**	*C. vencesi* (EN)
B. desperata (CR)	*Calumma andringitraense* (EN)	*C. vohibola* (EN)
B. ebenaui (VU)	*C. capuroni* (VU)	*Furcifer antimena* (VU)
B. exarmata (EN)	*C. cucullatum* (VU)	*F. balteatus* (EN)
B. karchei (EN)	*C. furcifer* (EN)	*F. belalandaensis* (CR)
B. lineata (EN)	*C. gallus* (EN)	*F. campani* (VU)
B. minima (EN)	*C. glawi* (EN)	*F. labordi* (VU)
B. perarmata (EN)	*C. hafahafa* (CR)	*F. nicosiai* (EN)
B. peyrierasi (EN)	*C. hilleniusi* (EN)	*F. rhinoceratus* (VU)
B. ramanantsoai (EN)	*C. jejy* (VU)	
B. tristis (EN)	*C. oshaughnessyi* (VU)	

Fig. 29: Threatened endemic Malagasy chameleons listed as Vulnerable and not yet held in zoos: *Brookesia ebenaui* (upper left), *Calumma oshaughnessyii* (upper right, photos: F. Glaw), *Furcifer campani* (lower left, photo: A. Crottini), *Palleon nasus* (lower right, photo: F. Glaw).

Tab. 16: Threatened Malagasy gecko (Gekkonidae) and plated lizard (Gerrhosauridae) species not yet kept in zoos according to ZIMS and ZTL analyses (threat status in brackets).

Gekkonidae	*Paragehyra gabriellae* (EN)	*U. malahelo* (EN)
Ebenavia maintimainty (EN)	*P. petiti* (VU)	*U. malama* (VU)
Lygodactylus bivittis (VU)	*Paroedura tanjaka* (EN)	*U. pietschmanni* (EN)
L. blanci (VU)	*Phelsuma antanosy* (CR)	**Gerrhosauridae**
L. intermedius (EN)	*P. masohoala* (CR)	*Zonosaurus anelanelany* (VU)
L. madagascariensis (VU)	*P. roesleri* (EN)	*Z. boettgeri* (VU)
L. mirabilis (CR)	*P. serraticauda* (EN)	*Z. subunicolor* (EN)
L. ornatus (EN)	*P. vanheygeni* (EN)	
L. roavolana (EN)	*Uroplatus guentheri* (EN)	

Tab. 17: Threatened Malagasy skink species (Scincidae) not yet kept in zoos according to ZIMS and ZTL analyses (threat status in brackets).

Scincinae	*Madascincus macrolepis* (EN)	*Pseudoacontias unicolor* (VU)
Brachyseps anosyensis (VU)	*M. nanus* (VU)	*Pygomeles petteri* (EN)
B. splendidus (VU)	*Paracontias fasika* (CR)	*Voeltzkowia mira* (EN)
Flexiseps alluaudi (VU)	*P. kankana* (VU)	*V. yamagishii* (EN)
F. ardouini (VU)	*P. minimus* (CR)	**Mabuyinae**
F. decaryi (EN)	*P. rothschildi* (CR)	*Trachylepis dumasi* (VU)
F. mandokava (VU)	*Pseudoacontias angelorum* (EN)	*T. lavarambo* (VU)
Madascincus arenicola (CR)	*P. menamainty* (CR)	*T. tavaratra* (VU)

Fig. 30: Threatened endemic Malagasy chameleons not held in zoos: *Calumma tarzan* (CR, top), *Brookesia perarmata* (EN, bottom, photos: F. Glaw).

Fig. 31: Threatened endemic Malagasy gekkonid and gerrhosaurid lizards listed as Endangered and not yet held in zoos: *Phelsuma roesleri* (top, photo: F. Glaw), *P. serraticauda* (middle, photo: A. Crottini), *Zonosaurus subunicolor* (bottom, photo: M. Vences).

Fig. 32: Threatened endemic Malagasy reptiles listed as Critically Endangered and not yet held in zoos: The skink species *Paracontias rothschildi* and *P. minimus*, as well as the snake species *Xenotyphlops grandidieri* all occurring in the same habitat in northernmost Madagascar (photo: J. Köhler).

Tab. 18: Threatened Malagasy snake species (Pseudoxyrophiidae and Xenotyphlopidae) not yet kept in zoos according to ZIMS and ZTL analyses (threat status in brackets).

Pseudoxyrophiidae	*Lycodryas citrinus* (VU)	*P. oblectator* (VU)
Alluaudina mocquardi (EN)	*L. guentheri* (EN)	*P. sokosoko* (VU)
Brygophis coulangesi (VU)	*L. inopinae* (EN)	*Thamnosophis martae* (EN)
Compsophis vinckei (CR)	*L. inornatus* (VU)	*T. stumpffi* (VU)
C. zeny (VU)	*Pararhadinaea melanogaster* (VU)	**Xenotyphlopidae**
Heteroliodon fohy (EN)	*Phisalixella variabilis* (EN)	*Xenotyphlops grandidieri (CR)*
Liophidium therezieni (VU)	*Pseudoxyrhopus ankafinaensis* (CR)	
Liopholidophis grandidieri (VU)	*P. kely* (EN)	

Fig. 33: Threatened endemic Malagasy snakes currently not yet held in zoos: *Lycodryas citrinus* (VU, left, photo: F. Glaw), *Phisalixella variabilis* (EN, right, photo: A. Crottini).

Discussion and recommendations

Of the 370 native amphibian species reported to occur in Madagascar, all are endemic. With this extraordinary amphibian endemism rate Madagascar is both one of the global hotspots of amphibian diversity, and among the top regions for amphibian conservation needs (Vieites et al., 2009; Vences & Raselimanana, 2018). The situation is similar for Madagascar's reptile diversity, with 420 species being endemic, resulting in a not less impressive endemism rate of approx. 98% (Glaw & Raselimanana, 2018). Currently, less than half (39%) of Madagascar's amphibian and less than a third (32%) of Madagascar's reptile species are evaluated as threatened by IUCN (2021). However, the knowledge on Madagascar's amphibian and reptile diversity is increasing rapidly, and there are continuous descriptions of new species being published both based on field work and revisions of species complexes. This result in higher species numbers and species with smaller distribution ranges (e.g, Raxworthy et al., 2003; Köhler et al., 2005; Glaw et al., 2010; Brown et al., 2016; Rakotoarison et al., 2017). As a consequence of this, the conservation status of many Malagasy taxa must be reassessed regularly, based on new scientific outcomes and increasing threats to biodiversity in Madagascar (e.g. Scherz et al., 2019; Prötzel et al., 2020). In addition, only recently described new species have not yet been evaluated by IUCN, but formal threat status is generally proposed in most of the original description, resulting in even more potentially threatened species that are not represented in zoos.

According to our analysis of ZIMS data, only 36 endemic Malagasy amphibian species (9.7%) (37 if considering the performed ZTL database analysis) are globally kept in zoos. Ten of them are threatened, which amounts to only 6.9% of the 135 endemic and threatened Malagasy amphibian species. However, it is worth noting that ZIMS entries / data change regularly. For example, at Cologne Zoo, the husbandry of *Dyscophus antongilii* and *Mantidactylus betsileanus* is still listed in the tables and figures of this paper, although it has been recently terminated. Instead, new endemic, threatened species reached this institution recently (*Mantella expectata*, *M. viridis* and *Scaphiophryne marmorata*), and these data are not yet included in the data of this paper, and the latter species already started breeding at Cologne Zoo in November 2021. In addition, not every ZIMS user regularly adds data to the database, and despite being the largest database available (used by around 1100 institutions worldwide; ZIMS, 2021), there are institutions that do not use ZIMS. Among the most important institutions breeding Malagasy amphibians and not yet included in ZIMS is the Malagasy Association Mitsinjo (Edmonds et al., 2012, 2015, 2016). Nonetheless, we believe ZIMS is a good representative of the actual situation (Leiss et al., 2021). As such, it is likely that more than the 93% of the threatened endemic

Malagasy amphibian species (135 species) currently do not benefit of any ex situ conservation component. Despite this gap, many more Malagasy amphibian species are currently kept in zoos in comparison to a survey performed in 2008 (37 versus 27; Garcia et al., 2008). Given that resources for long-term captive breeding are limited, priority should be given to threatened and micro-endemic species, in which the need for an emergency ex situ conservation breeding in future might have the highest likelihood. Besides that, also species that are husbandry analogues for other, threatened species, can play an important role, as they allow to develop skills for keeping and breeding species with similar requirements.

Our analysis revealed that there is a higher percentage of Malagasy reptile species in zoos in comparison with amphibians. Considering both ZIMS and ZTL analyses 97 endemic Malagasy reptile species (23%) are globally kept in zoos, 24 of which are threatened, which amounts to 18% of the 133 endemic Malagasy reptile species that are threatened. This implies that there are no ex situ conservation activities for 80% of the threatened endemic reptiles (106 species) from Madagascar at the time of this survey.

The paramount importance of ex situ conservation for Madagascar's vertebrates was stressed already decades ago (e.g. Benstead et al., 2003). In this paper, which deals with aquatic vertebrates (in particular fishes), the combination of deforestation, expanding agriculture, overfishing / depletion, and exotic species introduction has been highlighted to affect most of Madagascar's freshwater habitats, with captive breeding representing the only guaranteed means to save a large proportion of Madagascar's endemic freshwater fishes from extinction – despite persistence within the original habitat remains the optimal conservation strategy (Benstead et al., 2003; Andreone et al., 2005; Jenkins et al., 2014).

Of the 36 endemic Malagasy amphibian species and the 87 endemic reptile species kept in zoos worldwide according to ZIMS, only eleven amphibian species (30.5%) and 34 reptile species (38%) reproduced within the last 12 months. Finally, only four (36%) of the bred amphibian species were threatened taxa, and only thirteen (38%) of the reptile species bred were threatened.

Only *Mantella* representatives were successfully reproduced within the past 12 months. And of these, only *M. aurantiaca* and *M. viridis* were well reproducing in a number of institutions, although *M. expectata* was bred in two zoos and *M. madagascariensis* only in one, with a total of only 2 bred individuals. Such outcomes certainly are not sufficient for sustainable breeding programmes, as both a network of participating institutions and sufficient offspring numbers are necessary. However, as already stated by Garcia et al. (2008), the demand for continued breeding in some species can be low if they were successfully bred in the years before, and low breeding success does not necessarily mean lack of expertise with a particular species. Successful reproduction only appears in ZIMS if the clutch hatches, and individuals survive. Otherwise, the species could also succeed breeding but is decided to not progress with incubation, or it is not recommended to do so under the coordinator of the species (due for example to the lack of institutions to hold surplus, etc.). All these situations will not be reflected in ZIMS analyses and must be considered when interpreting the successful reproduction of a species under ZIMS. An example is the single bred radiated tortoise in Chester Zoo (UK) in Tab. 13. This is not due to limited breeding experience but rather because the EAZA Ex situ Programme (EEP) recommended not breeding this taxon to control the captive population, and the single individual in Chester Zoo was of an overlooked clutch with the young one once appearing on the exhibit.

Of the kept threatened Malagasy reptile species only representatives of the families Gekkonidae and Testudinidae were successfully reproduced within the past 12 months. A considerable number of institutions (16) reproduced *Astrochelys radiata* (in total 61 bred individuals) and ten institutions bred *Phelsuma klemmeri* (75 individuals) and *Uroplatus henkeli* (61 individuals). *Astrochelys yniphora* was the species with most individuals hatched (80), but in only a single institution, the Ampijoroa Chelonian Captive Breeding Centre (Madagascar), a centre established by Durrell Wildlife Conservation Trust specifically set up the captive breeding and release of this species. Reintroductions of *A. yniphora* were successful until they had to be stopped in 2017 due to extensive poaching pressures. The project is currently focusing on continued captive breeding as well as safeguarding of the last remaining wild ploughshare tortoises in a large and heavily guarded fenced-in natural enclosure (Goetz, 2019). All individuals kept outside of Madagascar derive from confiscations from the illegal pet trade and are kept in low numbers in only 12 institutions. This captive population is managed as a separate conservation unit for biosecurity reasons without any transfer of individuals to other institutions. As an exception, this captive colony was added to the ZIMS database in order to manage the studbook. In contrast, *A. radiata* is widely distributed among zoos and is kept in large numbers. Compared with amphibians, the outcomes for ex situ reptile projects are more successful, although they still need to be improved, as most of the remaining threatened species that reproduced in the past 12 months bred in less than 10 individuals. In addition, high breeding success in a threatened reptile taxon does not necessarily mean that offspring could be used for restocking programmes, as in some cases molecular identification is required and sometimes taxa are confused or mixed, for example in the case *Phelsuma grandis*/*P. madagascariensis* (see Tab. 9).

The success of captive breeding programmes remains low and could be improved through better exchange of individuals and information, optimised transfers, and a focus on species that have not yet been reproduced and for which husbandry knowledge has not yet been developed. This should also involve administered private breeding initiatives (Citizen Conservation, https://citizen-conservation.org/?lang=en), which can be a key to a successful and widespread conservation breeding programme for the herpetofauna of Madagascar (e.g. Garcia et al., 2008; Ziegler et al., 2020a, 2020b).

Our study revealed that brightly coloured and attractive species are preferentially kept, such as *Mantella*, *Dyscophus* and *Scaphiophryne* species among the amphibians (see also Garcia et al., 2008), all of which are also available for private use through the international pet trade.

The vast majority of the inconspicuous and less attractive amphibians have never been kept or bred in zoos or privately. This situation is unlikely to change in the near future, since such species are rarely or not at all exported from Madagascar. For conservation breeding efforts, however, it would be important that these species are also kept and bred under controlled conditions and their presentation/signage (so called story telling) could be highlighted in the public exhibitions, or as an alternative, their breeding facilities can be kept behind the scenes. To optimise management and conservation efforts in zoos, refocusing on threatened and micro-endemic species, and reviewing their stocks accordingly is highly recommended. To maintain the genetic diversity of captive populations, we recommend to establish more coordinated studbooks and monitoring programmes for threatened taxa, as too few are currently in place. For Malagasy reptiles, only some gecko, snake and turtle species are included in zoo programmes (see Tab. 19). Official zoo conservation breeding programmes for Malagasy amphibians are currently lacking. Garcia et al. (2008) suggested the captive breeding of *Mantella aurantiaca* to be attributed to the establishment of an (EAZA) studbook at that time; however, the species is still kept and bred in large numbers although the captive breeding programme does not exist anymore. Coordinated breeding programmes would be helpful to improve exchange and communication about success and failures between institutions holding species. For existing zoo populations of threatened endemic taxa from Madagascar, especially the populations of unknown origin, such as for confiscated individuals, genetic screening is recommended (e.g. Ziegler et al., 2020a), both to test the purity of the breeding and to obtain identifications and allocate them to geographical regions, a prerequisite for future repatriations and reintroductions of individuals or offspring (Le et al., 2020; Ziegler & Vences, 2021). In this way, confiscations will represent a chance to build up conservation breeding programmes (e.g. Rauhaus et al., 2021). A topical example is the studbook for *Uroplatus henkeli*, in the frame of which currently all the individuals are genetically tested for identification of origin, which is prerequisite for optimized breeding recommendations.

Tab. 19: Zoo breeding programmes for Malagasy herpetofauna representatives (AZA = Association of Zoos and Aquariums, EAZA = European Association of Zoos and Aquaria, JAZA = Japanese Association of Zoos and Aquariums, PAAZA = African Association of Zoos and Aquaria, ZAA = Zoo and Aquarium Association); according to ZIMS (ZIMS, 2021) and websites of AZA (https://www.aza.org), EAZA (https://www.eaza.net), JAZA (https://www.jaza.jp), PAAZA (https://www.zoosafrica.com), WAZA (https://www.waza.org), ZAA (https://www.zooaquarium.org.au). EEP = EAZA Ex situ Programme, ESB = European Studbook, ISB = International Studbook; SSP = Species Survival Plan® Programme, SAFE = Saving Animals From Extinction Programme.

AZA	EAZA
Uroplatus fimbriatus (SSP + Studbook)	*Astrochelys radiata* (EEP)
Uroplatus henkeli (SSP + Studbook)	*Astrochelys yniphora* (EEP)
Uroplatus phantasticus (SSP + Studbook)	*Pyxis arachnoides* (EEP)
Uroplatus sikorae (SSP + Studbook)	*Sanzinia madagascariensis* (ESB)
Astrochelys radiata (SAFE, SSP, Studbook)	*Uroplatus henkeli* (EEP)
Pyxis arachnoides arachnoides (SSP)	PAAZA
Pyxis arachnoides brygooi (SSP)	*Astrochelys radiata*
Pyxis arachnoides oblonga (SSP)	WAZA
Pyxis arachnoides Studbook (all subspecies)	*Astrochelys yniphora* (ISB)
Pyxis planicauda (SSP + Studbook)	ZAA
JAZA	*Astrochelys radiata*
Astrochelys	

According to ZIMS, and supported / visualized by our geographic coverage analyses, only zoos in Europe and North America are currently playing a major role in the husbandry of Malagasy herpetofauna, although they keep very varying numbers of specimens and diversities. There are no ZIMS records for Malagasy amphibians being kept in Australian/Oceanian and South American zoos. Similarly, only few reptile species are kept in these regions. In Africa and Asia only two endemic Malagasy amphibian species are kept, whereas reptiles are better represented (Africa: 15 species, Asia: 18 species kept). Thus, it would be desirable to extend conservation breeding networks to a global scale.

Breeding programmes should be designed to be long-term and sustainable. Animals should not be bought through the animal trade (see also Rabemananjara et al., 2008; Marshall et al., 2020) but preferably be obtained in exchange with other zoos or cooperation partners on site. If the pet trade is the only opportunity to get founder individuals for conservation breeding programmes, this should be discussed with authorities and approval should be obtained. Threatened species should not only be kept but also bred, and breeding should be achieved through conservation breeding networks, ideally over several generations (e.g. Garcia et al., 2008; Ziegler et al., 2020b). A good example is the case of *Uroplatus henkeli*, which was imported by Chester Zoo from AZA to form an EEP for the developing a sustainable breeding programme without the need to acquire animals from pet trade anymore. Similar imports of threatened taxa from AZA are planned by Chester Zoo to develop sustainable programmes in EAZA institutions. To achieve these goals, sufficient staff and expertise must be built up in zoos. If breeding successes are achieved, these should be published in scientific journals as breeding reports (e.g. Davies et al., 1999; Scheld et al., 2013) so that other institutions can benefit from the achieved knowledge and guarantee improved breeding successes. Many such studies on Malagasy taxa are available as contributions from private keepers (e.g. Weish, 1963; Mudrack, 1965, 1974; Siegenthaler, 1989; Ziegenhagen, 1981; Zimmermann, 1992; Ottensmann, 1993; Staniszewski, 1997a, 1997b; Dost, 1998; Staniszewski, 2001; Altenmüller, 2016) or from zoological research institutions (e.g. Pintak, 1987; Vences et al., 1996; Glaw et al., 1998, 2000; Schmidt et al., 2001; Scheld et al., 2013). However, in the case of amphibians most of these publications refer to the breeding of species of the genus *Mantella*, with only few contributions for other genera such as *Heterixalus*, *Mantidactylus*, *Boophis* and *Dyscophus*. In contrast, a large diversity of Malagasy reptile species are regularly kept and bred by hobbyist breeders over numerous generations, including tortoises (*Astrochelys radiata*, *Pyxis arachnoides*; e.g. Ahr, 2006), boas of the genera *Sanzinia* and *Acrantophis* (e.g. Borer, 2013), the colourful day geckos of the genus *Phelsuma* (e.g. Hallmann et al., 2008; Berghof, 2014), the bizarre leaf-tailed geckos of the genus *Uroplatus* (e.g. Gehring, 2020), and several other gecko genera like *Blaesodactylus*, *Ebenavia*, *Geckolepis*, *Lygodactylus* and *Paroedura* (eg. Schröder, 1987). *Paroedura* is increasingly bred as a laboratory model for studies in developmental biology, evolutionary ecology, physiology and genetics (e.g. Czarnoleski et al., 2017; Hara et al., 2018). Zoos could help significantly in the ex situ conservation mission and can make a greater contribution to filling knowledge and husbandry gaps in the future. They can make important contributions creating the know-how for keeping and breeding (e.g. Scheld et al., 2013; Edmonds et al., 2016), and can contribute using this knowledge for targeted conservation breeding programmes to prevent acutely threatened species from extinction. For example, little is known about the reproductive and developmental biology of most species, such as the cophyline microhylids in amphibians (e.g. Zimmermann & Zimmermann, 1994; Glaw et al., 2000; Oetter et al., 2001; Soariarimampionona et al., 2015). These often micro-endemic frogs, such as the dwarf species of the genus *Stumpffia*, which live in the leaf litter in rainforests and apparently have various forms of brood care (with or without foam nests, see Rakotoarison et al., 2017) should be prioritised, as almost nothing is known about them. Similarly, the arboricolous microhylid frogs of the genera *Platypelis* and *Cophyla*, which breed in water-filled tree holes (Glaw & Vences, 2007), have never been reproduced in captivity. In the last years it has been shown that the breeding of such tree cavity breeders is relatively easy when applying innovative terrarium equipment ("replacement caves"), and the behaviour can be observed and documented much more easily than in nature (e.g. Jungfer, 1996). Zoos and similar institutions can also play an important role in behavioural research and can contribute to make significant progresses in the development and success of conservation breeding.

Finally, field research in Madagascar must continue to uncover overlooked amphibian and reptile diversity before it is completely lost. This should also relate to conservation breeding efforts, as it is crucial to legally allow the receipt and transfer of threatened taxa to set up ex situ populations of species not held in captivity yet. A good example is the latest species action plan for *Mantella cowanii*, where one of the objectives is the ex situ component (Andreone et al., 2020). Ideally, this strategy should include both institutions keeping species ex situ in Madagascar, such as domestic breeding facilities, stations or zoos and institutions abroad. Very promising ex situ approaches have been made for amphibians and reptiles already, in particular by the Mitsinjo-breeding centre in Andasibe (e.g. Mattioli et al., 2006; Edmonds & Rakotoarisoa, 2012; Edmonds et al., 2012; Dawson et al., 2014; Edmonds et al., 2015; García & Edmonds, 2015; Edmonds et al., 2016; Rakotonanahary et al., 2017; Edmonds et al., 2021) and the Ampijoroa Chelonian Captive Breeding Centre. However, extension of insurance populations among various institutions abroad should be seen as an essential contribution to be better prepared for catastrophic events potentially affecting local facilities or natural populations, such as disease outbreaks, natural catastrophes or political unrests. Together such a strategy complies with the One Plan Approach proposed by the

IUCN SSC Conservation Breeding Specialist Group (CBSG), viz. the development of management strategies and conservation actions by all responsible parties for all populations of a species, whether inside or outside their natural range (e.g. Leiss et al., 2021). Any strategy must consider that ex situ measures can only prove successful together with a perspective for in situ conservation measures to protect and restore a species' natural habitat.

Outlook

There is a huge gap between the number of threatened endemic Malagasy amphibian and reptile taxa in the wild and the number of species held ex situ in zoological institutions. Only for a small percentage of threatened taxa conservation breeding programmes are in place and breeding outcome is often limited. In face of the ongoing deforestation, climate change, illegal animal trade and further threats to Malagasy biodiversity, to prevent accelerating extinction events before conservation measures can be functional in site, we suggest that ex situ measures are seen as a helpful tool to contribute saving species from extinction, as suggested by IUCN's One Plane Approach.

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Zusammenfassung

Unter schwierigen Umständen, z. B. wenn der In-situ-Schutz zu langsam umgesetzt werden kann und nicht ausreicht, um den Verlust von Lebensräumen und das Aussterben von Arten zu verhindern, können Ex-situ-Erhaltungszuchtansätze in der Zwischenzeit eine äußerst hilfreiche zusätzliche Schutzmaßnahme sein, bis die Bedrohungen und Probleme im natürlichen Lebensraum behoben sind. Insbesondere für Arten, die unmittelbar vom Aussterben bedroht sind, kann die Ex-situ-Erhaltungszucht das einzige zuverlässige Mittel sein, um sie vor dem Aussterben zu bewahren. Als bedeutende Naturschutzzentren mit globalen Netzwerken können Zoos einen wichtigen Beitrag leisten, indem sie Populationen von Arten erhalten, die aufgrund des zunehmenden Verlusts von Lebensräumen in freier Wildbahn oder durch die nachteiligen Auswirkungen neu auftretender Infektionskrankheiten oder invasiver Arten vom Aussterben bedroht sind. Ziel der aktuellen Studie war es, zu untersuchen, für welche bedrohten endemischen madagassischen Amphibien- und Reptilienarten bereits Ex-situ-Populationen in zoologischen Einrichtungen existieren und welche bedrohten Arten noch nicht durch Ex-situ-Erhaltungsmaßnahmen abgedeckt sind. Wir haben madagassische Amphibien- und Reptilienartenbestände in zoologischen Einrichtungen

erfasst, in dem wir die Anzahl der gehaltenen Arten, die Anzahl der Individuen pro Art, die Anzahl der Zoos, die eine Art halten, und die Zoos mit Zuchterfolgen in den letzten zwölf Monaten analysiert haben. Die Analysen erfolgten auf der Basis des Zoologischen Informations-Managementsystems (ZIMS, Species360, 2021), ergänzt durch Daten aus der europäischen Datenbank Zootierliste (ZTL). Darüber hinaus wurde eine Richness-Analyse durchgeführt, um herauszufinden, wie Zoos, die madagassische Amphibien- und Reptilienarten halten, weltweit verteilt sind. Madagaskar ist die Heimat von 370 endemischen Amphibien- und 420 endemischen Reptilienarten, mit einer außergewöhnlich hohen Endemismusrate von durchschnittlich ca. 98 %. Weniger als die Hälfte (39 %) der Amphibienarten Madagaskars und weniger als ein Drittel (32 %) der Reptilienarten Madagaskars werden aktuell von der IUCN (2021) als bedroht eingestuft. Gemäß unserer Analyse der ZIMS-Daten werden nur 36 endemische madagassische Amphibienarten (9,7 %) (37, wenn man Daten aus der ZTL-Datenbank berücksichtigt) weltweit in Zoos gehalten. Zehn von ihnen sind bedroht, was nur 6,9 % der 145 endemischen und bedrohten madagassischen Amphibienarten ausmacht. Es ist wahrscheinlich, dass für mehr als 93 % der bedrohten endemischen madagassischen Amphibien (135 Arten) derzeit noch keine Ex-situ-Erhaltungskomponente existiert. Unsere Analyse ergab, dass im Vergleich zu Amphibien verhältnismäßig mehr madagassische Reptilienarten in Zoos vertreten sind. Unter Berücksichtigung von ZIMS- und ZTL-Analysen werden weltweit 97 endemische madagassische Reptilienarten (23 %) in Zoos gehalten, von denen 27 bedroht sind, was 20 % der 133 bedrohten endemischen madagassischen Reptilienarten entspricht. Dies impliziert, dass es zu 80 % der bedrohten endemischen Reptilien (106 Arten) aus Madagaskar zum Zeitpunkt dieser Analyse keine Ex-situ-Erhaltungsschutzmaßnahmen gibt. Von den 36 endemischen madagassischen Amphibienarten und den 87 endemischen Reptilienarten, die weltweit laut ZIMS-Daten in Zoos gehalten werden, haben sich in den letzten zwölf Monaten nur elf Amphibienarten (30,5 %) und 34 Reptilienarten (39 %) vermehrt. Schließlich waren von den gezüchteten Amphibienarten nur vier (36 %) bedrohte Taxa, und von den gezüchteten Reptilienarten waren nur dreizehn (38 %) bedroht. Laut ZIMS und der durchgeführten Richness-Analyse spielen derzeit nur Zoos in Europa und Nordamerika eine größere Rolle in der Haltung der madagassischen Herpetofauna. Um die Management- und Erhaltungsbemühungen in Zoos zu optimieren, wird dringend empfohlen, sich auf bedrohte und mikro-endemische Arten zu konzentrieren und ihre Bestände entsprechend zu überprüfen. Für Amphibien und Reptilien wurden bereits sehr vielversprechende Ex-situ-Ansätze in Madagaskar unternommen, insbesondere vom Mitsinjo-Zuchtzentrum in Andasibe und vom Ampijoroa Chelonian Captive Breeding Centre. Die Ausweitung der Reservepopulationen auf verschiedene Institutionen im Ausland sollte jedoch als wesentlicher Beitrag angesehen werden, um besser auf katastrophale Ereignisse vorbereitet zu sein, die natürliche Populationen auslöschen bzw. lokale lokale Einrichtungen zerstören könnten, wie z. B. Krankheitsausbrüche, Naturkatastrophen oder politische Unruhen. Zusammengenommen entspricht eine solche Strategie dem One Plan Approach, der von der IUCN SSC Conservation Breeding Specialist Group (CBSG) vorgeschlagen wurde, nämlich die Entwicklung von Managementstrategien und Erhaltungsmaßnahmen durch alle verantwortlichen Parteien für alle Populationen einer Art, ob innerhalb oder außerhalb ihres natürlichen Verbreitungsgebiets. Jede Strategie muss dabei berücksichtigen, dass Ex-situ-Maßnahmen sich nur zusammen mit einer Perspektive für In-situ-Erhaltungsmaßnahmen zum Schutz und zur Wiederherstellung des natürlichen Lebensraums einer Art als erfolgreich erweisen können. Mit dieser Analyse wollen wir eine Grundlage für verbesserte Ex-situ-Erhaltungszuchtmaßnahmen schaffen und ein Erhaltungszuchtnetzwerk für die bedrohten endemischen Arten der madagassischen Herpetofauna entwickeln.

References

Ahr, P. (2006). Haltung und erfolgreiche Vermehrung der Madagassischen Spinnenschildkröte (*Pyxis arachnoides arachnoides*) Teil 2. Marginata 3(2), 40–48.

Ali, J.R., & Huber, M. (2010). Mammalian biodiversity on Madagascar controlled by ocean currents. Nature 463, 653–656.

Ali, J.R., & Vences, M. (2019). Mammals and long-distance over-water colonisation: The case for rafting dispersal; the case against phantom causeways. Journal of Biogeography 46, 2632–2636.

Altenmüller, A. (2016). Madagaskar-Buntfrösche. Die Gattung *Mantella*. Lebensweise, Haltung, Nachzucht. Natur und Tier-Verlag, 191 pages.

AmphibiaWeb. 2021. Available from https://amphibiaweb.org

Andreone, F. (Ed.). (2008). A conservation strategy for the amphibians of Madagascar. Museo Regionale di Scienze Naturali, Torino.

Andreone, F., Berg., P.E., Mercurio, V., & Rosa, G.M. (2013). Spatial ecology of *Scaphiophryne gottlebei* in the canyons of the Isalo Massif, Madagascar. Herpetologica 69, 11–21.

Andreone, F., Cadle, J.E., Cox, N., Glaw, F., Nussbaum, R.A., Raxworthy, C.J., Stuart, S., Vallan, D., & Vences M. (2005). Species review of amphibian extinction risks in Madagascar: conclusions from the Global Amphibian Assessment. Conservation Biology 19(6), 1790–1802.

Andreone, F., Carpenter, A.I., Copsey, J., Crottini, A., Jenkins, R.K.B., Köhler, J., Rabibisoa, N.H.C., Randriamahazo, H., & Raxworthy, C.J. (2012). Saving the diverse Malagasy amphibian fauna: Where are we four years after implementation of the Sahonagasy Action Plan? Alytes 29, 44–58.

Andreone, F., Carpenter, A.I., Cox, N., Du Preez, L., Freeman, K., et al. (2008). The challenge of conserving amphibian megadiversity in Madagascar. PLoS Biology 6, e118.

Auliya, M., Altherr, S., Ariano-Sanchez, D., Baard, E.H., Brown, C., Cantu, J.-C., Gentile, G., Gildenhuys, P., Henningheim, E., Hintzmann. J., Kanari, K., Krvavac, M., Lettink, M., Lippert, J., Luiselli, L., Nilson, G., Nguyen, T.Q., Nijman, V., Parham, J., Pasachnik, S.A., Pedrono, M., Rauhaus, A., Rueda, D., Sanchez, M.-E., Schepp, U., van Schingen, M, Schneeweiss, N., Segniagbeto, G.H., Shepherd, C., Stoner, S., Somaweera, R., Sy, E., Türkosan, O., Vinke, S., Vinke, T., Vyas, R., Williamson, S., & Ziegler, T. (2016). Trade in live reptiles, its impact on wild populations, and the role of the European market. Biological Conservation 204, 103–119.

Barrett, M., & Ratsimbazafy, J. (2009). Luxury bushmeat trade threatens lemur conservation. Nature 461, 470.

Benstead, J.P., de Rham, P.H., Gattolliat, J.-L., Gibon, F.M., Loiselle, P.V., Sartori, M., Sparks, J.S., & Stiassny, M.L.J. (2003). Conserving Madagascar's Freshwater Biodiversity. BioScience 53(11), 1101–1111.

Berghof, H.-P. (2014). Taggeckos der Gattung *Phelsuma*. Lebensweise, Haltung, Nachzucht. Natur und Tier-Verlag, 191 pp.

Bletz, M.C., Rosa, G.M., Andreone, F., Courtois, E.A., Schmeller, D.S., Rabibisoa, N.H.C., Rabemananjara, F.C.E., Raharivololoniaina, L., Vences, M., Weldon, C., Edmonds, D., Raxworthy, C.J., Harris, R.N., Fisher, M.C., & Crottini, A. (2015). Widespread presence of the pathogenic fungus *Batrachochytrium dendrobatidis* in wild amphibian communities in Madagascar. Scientific Reports 5, 8633.

Borer, M. (2013). Madagaskarboas: *Sanzinia* und *Acrantophis* – Lebensweise, Pflege und Fortpflanzung. KUS Verlag.

Brown, J.L., Sillero, N. Glaw, F. Bora, P., Vieites, D.R., & Vences, M. (2016). Spatial biodiversity patterns of Madagascar's amphibians and reptiles. PLoS ONE 11(1), e0144076.

Burney, D.A., Robinson, G.S., & Burney, L.P. (2003). *Sporormiella* and the late Holocene extinctions in Madagascar. Proceedings of the National Academy of Sciences of the USA 100, 10800–10805.

Burney, D., & Flannery, T. (2005). Fifty millennia of catastrophic extinctions after human contact. Trends in Ecology and Evolution 20, 395–401.

Conde, D.A., Flesness, N., Colchero, F., Jones, O.R., & Scheuerlein, A. (2011). An emerging role of zoos to conserve biodiversity. Science 331, 1390–1391.

Conde, D.A. (2013). The Role of Zoos. In: MacLeod, N., Archibald, J.D. & Levin, P. (Eds.): Grzimek's Animal Encyclopedia, Edition 2, Cengage Learning, 207–215.

Crottini, A., Brown, J.L., Mercurio, V., Glaw, F., Vences, M., & Andreone, F. (2012). Phylogeography of the poison frog *Mantella viridis* (Amphibia: Mantellidae) reveals chromatic and genetic differentiation across ecotones in northern Madagascar. Journal of Zoological Systematics and Evolutionary Research 50(4), 305–314.

Crottini, A., Chiari, Y., Mercurio, V., Meyer, A., Vences, M., & Andreone, F. (2008). Into the canyons: The phylogeography of the Malagasy frogs *Mantella expectata* and *Scaphiophryne gottlebei* in the arid Isalo Massif, and its significance for conservation (Amphibia: Mantellidae and Microhylidae). Organisms Diversity & Evolution 8, 368–377.

Crottini, A., Orozco-terWengel, P., Rabemananjara, F.C.E., Hauswaldt, J.S., & Vences, M. (2019). Mitochondrial introgression, color pattern variation and severe demographic bottlenecks in three species of Malagasy poison frogs, genus *Mantella*. Genes 10, 317.

Czarnoleski, M., Labecka, A.M., Starostová, Z., Sikorska, A., Bonda-Ostaszewska, E., Woch, K., Kubička, L., Kratochvíl, L., & Kozlowski, J. (2017). Not all cells are equal: Effects of temperature and sex on the size of different cell types in the Madagascar ground gecko *Paroedura picta*. Biology Open 6, 1149–1154.

Davies, R., Davies, V., & Hoskisson, P. (1999). An account of the care and breeding of *Heterixalus alboguttatus* (Boulenger, 1882), along with a description of the tadpole. British Herpetological Society Bulletin 66, 26–30.

Dawson, J., Edmonds, D., Freeman, K., Iambana, B., Moore, M., & Rakotoarisoa, J.C. (2014). Working together to develop Madagascar's amphibian captive breeding capacity. FrogLog 22, 61–62.

Dost, U. (1998). Buntfrösche von Madagaskar. Zur Pflege und Zucht von *Mantella*-Arten. Das Aquarium 6/1998(348), 50–53.

Dufils, J.M. (2003). Remaining forest cover. In: Goodman, S.M., & Benstead, J.P. (Eds): The natural history of Madagascar. The University of Chicago Press, Chicago, Illinois, 88–96.

Edmonds, D., & Rakotoarisoa, J.C. (2012). Ex-situ amphibian conservation in the frog capital of Madagascar. FrogLog 103, 32–34.

Edmonds, D., Rakotoarisoa, J.C., Dolch, R., Pramuk, J., Gagliardo, R., Andreone, F., Rabibisoa, N., Rabemananjara, F.C.E., Rabesihanaka, S., & Robsomanitrandrasana, E. (2012). Building capacity to implement conservation breeding programs for frogs in Madagascar: Results from year one of Mitsinjo's amphibian husbandry research and captive breeding facility. Amphibian and Reptile Conservation 5, 57–69.

Edmonds, D., Rakotoarisoa, J.C., Rasoanantenaina, S., Sam, S.S., Soamiarimampionona, J., Tsimialomanana, E., Youssouf, Dolch, R., Rabemananjara, F., Rabibisoa, N., & Robsomanitrandrasana, E. (2015). Captive husbandry, reproduction, and fecundity of the golden mantella (*Mantella aurantiaca*) at the Mitsinjo breeding facility. Salamandra 51, 315–325.

Edmonds, D., Rakotoarisoa, J.C., Rasoanantenaina, S., Sam, S.S., Soamiarimampionona, J., & Tsimialomanana, E. (2016). Captive management and reproduction of the treefrog *Boophis pyrrhus* in Andasibe, Madagascar. Herpetological Review 47, 405–409.

Edmonds, D., Andreone, F., & Crottini, A. (2021). Madagascar: An Amphibian Hotspot and the Conservation of the Harlequin *Mantella* Frog. In: Reference Module in Earth Systems and Environmental Sciences.

Farhadinia, M.S., Johnson, P.J., Zimmermann, A., McGowan, P.J.K., Meijaard, E., Stanley-Price, M., & Macdonald, D.W. (2020). Ex situ management as insurance against extinction of mammalian megafauna in an uncertain world. Conservation Biology 34(4), 988–996.

Frost, D.R. (2021). Amphibian Species of the World: an Online Reference. Version 6.1. Electronic Database accessible at https://amphibiansoftheworld.amnh.org/index.php. American Museum of Natural History, New York, USA.

Ganzhorn, J.U., Lowry, P.P. II, Porter, P., Schatz, G., & Sommer, S. (2008). The biodiversity of Madagascar: one of the world's hottest hotspots on its way out. Oryx 35, 346–348.

Ganzhorn, J.U., Mercier, J.-L., & Wilmé, L. (2016). Inseln als Modelle für Evolution: Zusammenleben und Schutz von Biodiversität am Beispiel Madagaskar. In: Schickhoff, U. (Ed.): Biogeographie und Biodiversität. Hamburg 2016 (Hamburger Symposium Geographie, Band 8), 39–57.

Garcia, G., Bock, L., Earle, S., Berridge, R., & Copsey, J. (2008). Captive breeding as a tool for the conservation of Malagasy amphibians: How ready are we to respond to the need? In: Andreone, F. (Ed.): A conservation strategy for the amphibians of Madagascar. Torino: Museo Regionale di Scienze Naturali di Torino, 321–342

García, G., & Edmonds, D. (2015). Captive breeding and ex situ conservation of Malagasy amphibians. In: G.M. Rosa, J.E. Cadle, A. Crottini, J. Dawson, D. Edmonds, M.C. Fisher, G. García, F. Glaw, J. Glos, R.N. Harris, J. Köhler, F. Rabemananjara, S. Rabesihanaka, N. Rabibisoa, J.C. Randrianantoandro, A.P. Raselimanana, C.J. Raxworthy, H. Razafindraibe, D. Vallan, M. Vences, C. Weldon, P.C. Wright, & F. Andreone (Eds), ACSAM2, A Conservation Strategy for the Amphibians of Madagascar 2. Museo Regionale di Scienze Naturali, Regione Piemonte, Torino, 27.

Gehring, P.-S. (2020). Plattschwanzgeckos – Die Gattung *Uroplatus*. Edition Chimaira, 383 pp.

Glaw, F., Köhler, J., de la Riva, I., Vieites, D.R., & Vences, M. (2010). Integrative taxonomy of Malagasy treefrogs: combination of molecular genetics, bioacoustics and comparative morphology reveals twelve additional species of *Boophis*. Zootaxa 2383, 1–82.

Glaw, F., & Raselimanana, A.P. (2018). Systématique des reptiles terrestres malgaches (ordres: Squamata, Testudines et Crocodylia)/Systematics of terrestrial Malagasy reptiles (Orders Squamata, Testudines, and Crocodylia). In: Goodman, S.M., Raherilalao, M.J., & Wohlhauser, S. (Eds): Les aires protégées terrestres de Madagascar: Leur histoire, description et biote/The terrestrial protected areas of Madagascar: Their history, description, and biota. Association Vahatra, Antananarivo, 289-327.

Glaw, F., Schmidt, K., & Vences, M. (1998). Erstzucht von *Mantella laevigata*. TI Magazin 140(2/98), 61–64.

Glaw, F., & Vences, M. (2007). A Field Guide to the Amphibians and Reptiles of Madagascar, third edition. Vences & Glaw Verlag.

Glaw, F., Vences, M., & Schmidt, K. (2000). Nachzucht, Juvenilfärbung und Oophagie von *Mantella laevigata* im Vergleich zu anderen Arten der Gattung (Amphibia: Ranidae). Salamandra 36, 1–24.

Goetz, M. (2019). EAZA Best Practice Guidelines for the Ploughshare tortoise, *Astrochelys yniphora* – First edition. European Association of Zoos and Aquariums, Amsterdam, The Netherlands

Goodman, S.M., & Benstead, J.P. (Eds) (2003). The Natural History of Madagascar, University of Chicago Press.

Graf, R., Pfleiderer, J., Fritsche, M., Schmidt, J., Mantei, R., Peter, S.P., & Spangenberg, F. (2021). Zootierliste. URL: www.zootierliste.de.

Groombridge, B., & Jenkins, M. (1998). Freshwater Biodiversity: A Preliminary Global Assessment. Cambridge (United Kingdom). World Conservation Monitoring Centre (WCMC), World Conservation Press. WCMC Biodiversity Series, 8.

Hallmann, G., Krüger, J., & Trautmann, G. (2008). Faszinierende Taggeckos. Die Gattung *Phelsuma* (2. Auflage). Natur und Tier-Verlag, 253 pp.

Hara, Y., Takeuchi, M., Kageyama, Y., Tatsumi, K., Hibi, M., Kiyonari, H., & Kuraku, S. (2018). Madagascar ground gecko genome analysis characterizes asymmetric fates of duplicated genes. BMC Biology 16, 40.

Harper, G.J., Steininger, M.K., Tucker, C.J., Juhn, D., & Hawkins, F. (2007). Fifty years of deforestation and forest fragmentation in Madagascar. Environmental Conservation 34, 325–333.

Henderson, A., Clark, G., Haberle, S., Higham, T., Nowak-Kemp, M., Prendergast, A., Radimilahy, C., Rakotozafy, L.M., Ramilisonina, Schwenninger, J.L., Virah-Sawmy, M., & Camens, A. (2018). New evidence of megafaunal bone damage indicates late colonisation of Madagascar. PLoS ONE 13, 1–14.

IUCN (2021). The IUCN Red List of Threatened Species. Version 2021-2. IUCN Species Survival Commission. Retrieved from https://www.iucnredlist.org/

Jenkins, R.K.B, Tognelli, M.F., Bowles, P., Cox, N., Brown, J.L., Chan, L, Andreone, F., Andriamazava, A., Andriantsimanarilafy, R.R., Anjeriniaina, M., Bora, P., Brady, L.D., Hantalalaina, E.F., Glaw, F., Griffiths, R.A., Hilton-Taylor, C., Hoffmann, M., Katariya, V., Rabibisoa, N.H., Rafanomezantsoa, J., Rakotomalala, D., Rakotondravony, H., Rakotondrazafy, N., Ralambonirainy, J., Ramanamanjato, J.B., Randriamahazo, H., Randrianantoandro, J.C., Randrianasolo, H.H., Randrianirina, J.E., Randrianizahana, H., Raselimanana, A.P., Rasolohery, A., Ratsoavina, F.M., Raxworthy, C.J., Robsomanitrandrasana, E., Rollande, F., van Dijk, P.P., Yoder, A.D., & Vences, M. (2014). Extinction risks and the conservation of Madagascar's reptiles. PLoS ONE 9(8), e100173.

Jungfer, K.-H. (1996). Reproduction and parental care of the coronated treefrog, *Anotheca spinosa* (Steindachner, 1864) (Anura: Hylidae). Herpetologica 52(1), 25–32.

Köhler, J., Vieites, D.R., Bonett, R.M., García, F.H., Glaw, F., Steinke, D., & Vences, M. (2005). New amphibians and global conservation: a boost in species discoveries in a highly endangered vertebrate group. Bioscience 55(8), 693–696.

Le, M.D., McCormack, T.E.M., Hoang, H.V., Duong, H.T., Nguyen, T.Q., Ziegler, T., Nguyen, H.D., & Ngo, H.T. (2020). Threats from wildlife trade: The importance of genetic data in safeguarding the endangered four-eyed turtle (*Sacalia quadriocellata*). Nature Conservation 41, 91–111.

Leiss, L., Rauhaus, A., Rakotoarison, A., Fusari, C., Vences, M., & Ziegler, T. (2021). Review of threatened Malagasy freshwater fishes in zoos and aquaria: The necessity of an ex situ conservation network – a call for action. Zoo Biology.

Licata, F., Andreone, F., Freeman, K., Rabesihanaka, S., Robsomanitrandrasana, E., Reardon, J., & Crottini, A. (2020). The Asian Toad (*Duttaphrynus melanostictus*) in Madagascar: A Report of an Ongoing Invasion. – In: Angelici, F.M. & Rossi, L. (Eds): Problematic Wildlife II, New Conservation and Management Challenges in the Human-Wildlife Interactions. Springer, Berlin, Germany, 617-638.

Licata, F., Ficetola, G.F., Freeman, K., Mahasoa, R., Ravololonarivo, V. & Fidy, J., Koto-Jean, A., Nahavitatsara, E., Andreone, F., & Crottini, A. (2019). Abundance, distribution and spread of the invasive Asian toad *Duttaphrynus melanostictus* in eastern Madagascar. Biological Invasions 21, 1615–1626.

Licata, F., Harison, R.F., Ficetola, G.F., Freeman, K., Muller, B.J., Rodriguez Ponga, V., Andreone, F., & A. Crottini (2022): Toad invasion of Malagasy forests triggers severe mortality of predatory snakes. – Biological Invasions. https://doi.org/10.1007/s10530-021-02708-z.

Loiselle, P.V. (2003). Captive breeding for the freshwater fishes of Madagascar. In: Goodman, S.M., & Benstead, J.P. (2003). The Natural History of Madagascar. Chicago: University of Chicago Press, 1569–1574.

Lowry, P.P. II, Schatz, G.E., & Phillipson, P.B. (1997). The classification of natural and anthropogenic vegetation in Madagascar. In: Goodman, S.M., & Patterson, B.D. (Eds.): Natural Change and Human Impact in Madagascar. Smithsonian Institution Press, Washington DC.

Marshall, B.M., Casewell, N.R., Vences, M., Glaw, F., Andreone, F., Rakotoarison, A., Zancolli, G., Woog, F., & Wüster W. (2018). Widespread vulnerability of Malagasy predators to the toxins of an introduced toad. Current Biology 28, R654–R655.

Marshall, B.M., Strine, C., & Hughes, A.C. (2020). Thousands of reptile species threatened by under-regulated global trade. Nature Communications 11 (4738), 1–12.

Masters, J.C., Génin, F., Zhang, Y., Pellen, R., Huck, T., Mazza, P.P.A., Rabineau, M., Doucouré, M., & Aslanian, D. (2020). Biogeographic mechanisms involved in the colonisation of Madagascar by African vertebrates: Rifting, rafting and runways. Journal of Biogeography (in press).

Mattioli, F., Gili, C., & Andreone, F. (2006). Economics of captive breeding applied to the conservation of selected amphibian and reptile species from Madagascar. Natura–Società italiana di Scienze naturali e Museo civico di Storia Naturale di Milano 95(2), 67–80.

Morelli, T.L., Smith, A.B., Mancini, A.N., et al. (2020). The fate of Madagascar's rainforest habitat. Nature Climate Change 10, 89–96.

Mudrack, W. (1965). Pflege und Zucht des Goldfröschchens, *Mantella aurantiaca*. Die Aquarien- und Terrarienzeitschrift (DATZ) 18(10), 312–313.

Mudrack, W. (1974). Haltung und Zucht des Goldfröschchens, *Mantella aurantiaca* Mocquard, 1900. Das Aquarium 8(58), 160–161.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., & Kents, J. (2000). Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

Ndriantsoa, S., Rakotoarison, A., Rakotonanahary, T., Andreone, F., Crottini, A., & Dawson, J. (2018). A Conservation Strategy for the Amphibians of Madagascar: where are we now? FrogLog 26(1), 11–12.

Oetter, K., Wanke, S., & Vences, M. (2001). Ergänzende Daten zur Larvalentwicklung von *Mantella laevigata* Methuen and Hewitt, 1913 (Amphibia: Mantellidae). Salamandra 37, 99–104.

Oksanen, J., Guillaume Blanchet, F., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., Szoecs, E., & Wagner, H. (2020). vegan: Community Ecology Package. R package version 2.5-7. https://CRAN.R-project.org/package=vegan

Ottensmann, M.S. (1993). *Mantella crocea* – Terrarienhaltung, Verhaltensbeobachtungen und Nachzucht. Herpetofauna 15(85), 27–30.

Passal, M. (2015). Microendemic species: can they be saved? Conservation Biology News. URL: https://conservationbiologynews.wordpress.com/2015/10/22/microendemic-species-can-they-be-saved/ (03.08.2020).

Pintak, T. (1987). Zur Kenntnis des Tomatenfrosches *Dyscophus antongilii* (Grandidier 1877). Salamandra 23(2/3), 106–121.

Prötzel, D., Scherz, M.D., Ratsoavina, F.M., Vences, M., & Glaw, F. (2020). Untangling the trees: Revision of the *Calumma nasutum* complex (Squamata: Chamaeleonidae). Vertebrate Zoology 70(1), 23–59.

Rabemananjara, F.C.E., Raminosoa, N., Rasoamampionona Ramilijaona, O., Andreone, F., Bora, P., Carpenter, A., Glaw, F., Razafindrabe, T., Vallan, D., Vieites, D.R., & Vences, M. (2008). Malagasy poison frogs in the pet trade: a survey of levels of exploitation of species in the genus Mantella. In: Andreone, F. (Ed.): A Conservation Strategy for the Amphibians of Madagascar. Monografie del Museo Regionale di Scienze Naturali di Torino 45, 277–299.

Rakotoarison, A., Scherz, M.D., Glaw, F., Köhler, J., Andreone, F., Franzen, M., Glos, J., Hawlitschek, O., Jono, T., Mori, A., Ndriantsoa, S.H., Rasoamampionona, N.R., Riemann, J.C., Rödel, M.O., Rosa, G.M., Vieites, D.R., Crottini, A., & Vences, M. (2017). Describing the smaller majority: integrative taxonomy reveals twenty-six new species of tiny microhylid frogs (genus *Stumpffia*) from Madagascar. Vertebrate Zoology 67(3), 271–398.

Rakotonanahary, T.F., Dawson, J., Andreone, F., Rakotoarisoa, J.C., & Edmonds, D. (2017). Amphibian captive breeding programs for Madagascar: Where we are now and the road ahead. FrogLog 25(118) 37–39.

Rauhaus, A., Niggemann, C., Nicolaudius, J., & Ziegler, T. (2021). Haltung und Nachzucht der vom Aussterben bedrohten Burmesischen Sternschildkröte *Geochelone platynota* im Kölner Zoo, Deutschland. Sauria 43(2), 13–26.

Raxworthy, C.J., Martinez-Meyer, E., Horning, N., Nussbaum, R.A., Schneider, G.E., Ortega-Huerta, M.A., & Townsend Peterson, A. (2003). Predicting distributions of known and unknown reptile species in Madagascar. Nature 426(6968), 837–841.

Scheld, S., Perl, R.G.B., Rauhaus, A., Karbe, D., van Der Straeten, K., Hauswaldt, J.S., Randrianiaina, R.D., Gawor, A., Vences, M., & Ziegler, T. (2013). Larval morphology and development of the Malagasy frog *Mantidactylus betsileanus*. Salamandra 49(4), 186–200.

Scherz, M.D., Glaw, F., Hutter, C.R., Bletz, M.C., Rakotoarison, A., Köhler, J., & Vences, M. (2019). Species complexes and the importance of Data Deficient classification in Red List assessments: The case of *Hylobatrachus* frogs. PLOS ONE 14(8), e0219437.

Schmidt, K., Glaw, F., & Vences, M. (2001). Die Madagassischen Riedfrösche der Gattung *Heterixalus*. Reptilia 6(6), 71–78.

Schröder, E. (1987). Beobachtungen an 16 Nachzuchtgenerationen des madagassischen Geckos *Paroedura pictus* (Peters, 1854). Salamandra 23(4), 236–240.

Siegenthaler, R. (1989). Die Aufzucht des madagassischen Goldfröschchens *Mantella aurantiaca*. Herpetofauna 11(60), 32–34.

Soariarimampionona, J., Sam, S.S., Dolch, R., Klymus, K., Rabemananjara, F., Robsomanitrandrasana, E., Rakotoarisoa, J.C., & Edmonds, D. (2015). Effects of three diets on development of *Mantidactylus betsileanus* larvae in captivity. Alytes 32, 7–15.

Staniszewski, M. (1997a). Guide to Owning a *Mantella*. T.F.H. Publications Inc., USA.

Staniszewski, M. (1997b). Successful care of Mantellas. Reptile Hobbist, June 1997, 10–18.

Staniszewski, M.S. (2001). Mantellas. Edition Chimaira, Frankfurt a. M., 229 pp.

Strömberg, C.A.E. (2011). Evolution of grasses and grassland ecosystems. Annual Review of Earth and Planetary Sciences 39, 517–544.

Tavaszi, J. (2019). Haltung und Nachzucht von Boophis albilabris. Reptilia 24 (139), 44–48.

Uetz, P., Freed, P., Aguilar, R., & Hosek, J. (Eds) (2021). The Reptile Database, http://www.reptile-database.org.

Vences, M., Köhler, J., Schmidt, K. & Glaw, F. (1996). *Mantella betsileo*: Haltung, Nachzucht und Farbvarianten. DATZ 49(9), 579–582.

Vences, M., & Raselimanana, A.P. (2018). Systématique des amphibiens malgaches (Amphibia: Anura)/Systematics of Malagasy amphibians (Amphibia: Anura). In: Goodman, S.M., Raherilalao, M.J. & Wohlhauser, S. (Eds): Les aires protégées terrestres de Madagascar: Leur histoire, description et biote/The terrestrial protected areas of Madagascar: Their history, description, and biota. In: Goodman, S.M., Raherilalao, M.J. & Wohlhauser, S. (eds.) Association Vahatra, Antananarivo, 257–288.

Vieites, D.R., Wollenberg, K.C., Andreone, F., Köhler, J., Glaw, F., & Vences, M. (2009). Vast underestimation of Madagascar's biodiversity evidenced by an integrative amphibian inventory. Proceedings of the National Academy of Sciences of the United States of America 106, 8267–8272.

Virah-Sawmy, M. (2009). Ecosystem management in Madagascar during global change. Conservation Letters 2, 163–170.

Watson, J.E.M., Joseph, L.N., & Fuller, R.A. (2010). Mining and conservation: implications for Madagascar's littoral forests. Conservation Letters 3, 286–287.

Wayre, P. (1969). The role of zoos in breeding threatened species of mammals and birds in captivity. Biological Conservation 2, 47–49.

Weish, P. (1963). Pflege und Zucht des Goldfröschchens (*Mantella aurantiaca*). Die Aquarien- und Terrarienzeitschrift (DATZ) 16, 149–150.

Weldon, C., Crottini, A., Bollen, A., Rabemananjara, F.C.E., Copsey, J., Garcia, G., & Andreone, F. (2013). Preemptive National Monitoring Plan for Detecting the Amphibian Chytrid Fungus in Madagascar. Ecohealth 10, 234–240.

Wilmé, L., Goodman S.M., & Ganzhorn, J.U. (2006). Biogeographic evolution of Madagascar's microendemic biota. Science 312, 1063–1065.

Ziegenhagen, J. (1981). Durch Nachzucht erhalten: *Mantella cowani.* Aquarien-Magazin 15, 566–569.

Ziegler, T., Frank-Klein, N., Ommer, S., Hürche, R., Loiselle, P.V., & Vences, M. (2020a). Keeping and breeding of threatened endemic Malagasy freshwater fishes at Cologne Zoo (Germany): a contribution towards the advancement of a conservation breeding network. Der Zoologische Garten 88, 123–155.

Ziegler, T., Rauhaus, A., Niggemann, C., Nicolaudius, J., Bernardes, M., & Nguyen, T.Q. (2020b). Developing a conservation breeding network for threatened Vietnamese Crocodile Newts. AArk Newsletter Nr. 52, 9–12.

Ziegler, T., & Vences, M. (2020). Molecular identification of water monitors (*Varanus salvator* complex) from confiscations and the pet trade, including phylogenetic placement of *V. s. ziegleri* – a molecular reference for species conservation enforcement and conservation breeding. Der Zoologische Garten 88, 31–50.

Zimmermann, H. (1992). Nachzucht und Schutz von *Mantella crocea*, *Mantella viridis* und vom madagassischen Goldfröschchen *Mantella aurantiaca*. Zeitschrift des Kölner Zoo 35(4), 165–171.

Zimmermann, E., & Zimmermann, H. (1994). Reproductive strategies, breeding, and conservation of tropical frogs: Dart-poison frogs and Malagasy poison frogs. In: Murphy, J.B., Adler, K. & Collins, J.T. (Eds): Captive Management and Conservation of Amphibians and Reptiles. Society for the Study of Amphibians and Reptiles, Ithaca (New York). Contributions to Herpetology 11, 255–266.

ZIMS (2021). Species360 Zoological Information Management System, zims.Species360.org.

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New records of threatened leaf chameleons highlight unexpected genetic diversity of the *Brookesia decaryi/B. bonsi* species complex in western Madagascar

Neue Nachweise von gefährdeten Stummelschwanz-chamäleons offenbaren eine unerwartete genetische Diversität im *Brookesia decaryi/B. bonsi*-Artenkomplex im westlichen Madagaskar

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Abstract

The poorly known Malagasy leaf chameleons *Brookesia decaryi* and *B. bonsi* are considered as closely related and are classified on the IUCN Red List of threatened species as Endangered and Critically Endangered, respectively. Prompted by the discovery of a new coastal *Brookesia* population morphologically similar to *B. decaryi*, we studied the genetic variation of the *Brookesia decaryi/B. bonsi* complex from western Madagascar using two mitochondrial genes. Our phylogenetic analysis demonstrates unexpected discrepancies between the phylogenetic position and the morphology of the different populations and points to a complex situation re-

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garding their evolutionary history. Our results suggest that the *B. bonsi* complex is not endemic to the Namoroka reserve but widespread in western Madagascar, and confirm that *B. decaryi* is likely endemic to the Ankarafantsika National Park. The newly discovered coastal population is genetically distinct and its habitat should be protected. Further studies are necessary to revise the taxonomy, distribution, and the conservation status of this species complex.

Among Madagascar's leaf chameleons of the genus *Brookesia* one clade containing *B. bonsi, B. brunoi, B. brygooi, B. decaryi* and *B. perarmata* (Crottini et al., 2012; Tolley et al., 2013) is distributed across dry deciduous forests and relics of more humid forests in western Madagascar (Glaw & Vences, 2007). While the poorly known *B. bonsi* is considered endemic to the karstic limestone area of Namoroka, *B. decaryi* appears to be restricted to Ankarafantsika National Park, *B. brunoi* has only been recorded from the private Anja Reserve, and the morphologically highly distinct *B. perarmata* is endemic to the limestone karst of Tsingy de Bemaraha National Park (Ramanantsoa, 1980; Glaw & Vences, 2007; Bora et al., 2010; Jenkins et al., 2011; Crottini et al., 2012). Numerous herpetological surveys in western Madagascar have failed to record these four species elsewhere (e.g., Raselimanana, 2008; Rakotoarison et al., 2015; Cocca et al., 2018; Belluardo et al., 2021). In contrast, *B. brygooi* is widespread across western Madagascar, and occurs syntopically with *B. decaryi* at Ankarafantsika (Mori et al., 2014).

Because remaining dry forests in northwestern and western Madagascar are under high anthropogenic pressure (Waeber et al., 2015), several of these microendemic chameleons are classified as threatened by the IUCN Red List. *Brookesia brunoi* is considered Near Threatened, *B. decaryi* and *B. perarmata* Endangered and *B. bonsi* Critically Endangered (Jenkins et al., 2014), and only the widespread *B. brygooi* is classified as Least Concern.

For *Brookesia decaryi*, the suitable deciduous dry forest occurs throughout Ankarafantsika and accordingly the chameleon's extent of occurrence was estimated to be 1,300 km², the area

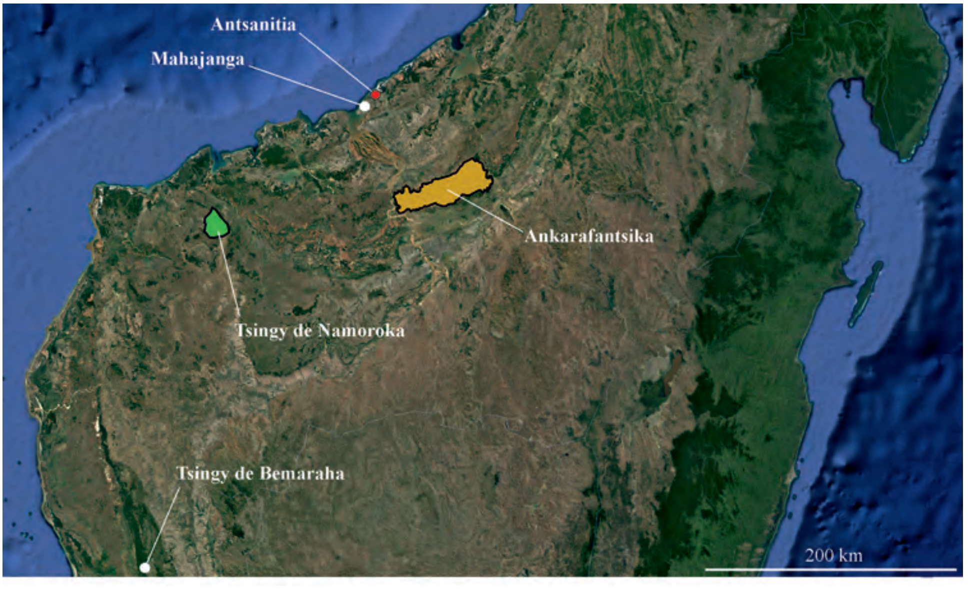

Fig. 1: Distribution map showing the ranges of *Brookesia bonsi* (green) and *B. decaryi* (beige) according to the IUCN Red List, complemented by the localities of *B*. aff. *bonsi* A (Tsingy de Bemaraha; white circle) and *B*. aff. *bonsi* B (Antsanitia; red circle). Map from Google Earth

Fig. 2: *Brookesia* aff. *bonsi* B from the coastal deciduous dry forest remains near Antsanitia, northwestern Madagascar. (A–C) adult individuals in the leaf litter; (D–E) subadult and juvenile, roosting in the vegetation at night. Note that these specimens morphologically remind *B. decaryi* (Fig. 4) in their relatively wide body, distinct lateral skin folds, and the indistinct supernasal cone. Photos: F. Glaw

of the national park (Fig. 1), but continuing decline in the quality of the habitat due to cattle grazing, fire and charcoal collection led to its classification as "Endangered" by the IUCN Red List of Threatened Species (Jenkins et al., 2011). Continuing pressures on the forest of Ankarafantsika, such as logging and fires, have reduced forest cover and increased its fragmentation (Steffens et al., 2020). In September and October 2021 the southern portion of the reserve was affected by unprecedented fires, burning more than 40 square kilometers (Carver, 2021).

During herpetological surveys in coastal northwestern Madagascar we recorded several chameleons phenotypically similar to *B. decaryi* (Fig. 2). These specimens were captured in the evening of 28 March 2018 near the Antsanitia hotel (15.57716°S, 46.43378°E, 6 m a.s.l.), ca. 20 km northeast of Mahajanga, in an unprotected dry forest close to the mouth of a river. Additional individuals (several subadults and one adult) were observed (but not collected) in a disturbed dry forest on 10 and 13 March 2020 between 15.56947°S, 46.42944°E, 12 m a.s.l. and 15.57086°S, 46.42969°E, 18 m a.s.l. The shortest airline distance between these new localities and Ankarafantsika is approx. 78 km. Two collected voucher individuals were deposited in the Zoologische Staatssammlung München (Germany) for further studies (ZSM 216–217/2018).

The Antsanitia leaf chameleons were found roosting at night on branches and leaves in moderately high densities approx. 10–30 cm above the ground, as is typical for *B. decaryi* (Razafimahatratra et al., 2008). ZSM 216/2018 (field number FGZC 5709, juvenile) measured 54.5 mm total in length (36.4 mm snout-vent length) and ZSM 217/2018 (FGZC 5710, probably subadult female) measured 69.7 mm total in length (44.1 mm snout-vent length). Other chameleon species found in the dry forest remains around Antsanitia were *Furcifer angeli* and *F. oustaleti*. We also observed four species of snakes (*Acrantophis madagascariensis, Sanzinia volontany, Madagascarophis colubrinus, Mimophis occultus*), two species of geckos (*Lygodactylus* sp., *Phelsuma kochi*), two species of skinks (*Trachylepis elegans, Voetzkowia mira*) and one species of freshwater turtle (*Pelusios castanoides*), the latter had been captured by local children.

To ascertain the identity of the new *Brookesia* population at Antsanitia, we sequenced segments of the mitochondrial genes for subunit 2 and subunit 4 of the NADH Dehydrogenase (ND2 and ND4), using primers and protocols as in Tolley et al. (2013). New sequences were combined with previously available sequences of the *B. decaryi* complex (Table 1), aligned and concatenated with Concatenator, which is part of the iTaxoTools suite of programs (Vences et al., 2021), and analysed under the Maximum Likelihood optimality criterion in MEGA 7 (Kumar et al., 2016). All new sequences were submitted to GenBank; see Table 1 for accession numbers.

The resulting tree (Fig. 3) surprisingly revealed that the Antsanitia specimens did not form a clade with the morphologically similar *B. decaryi* (Fig. 4) from the type locality (Ankarafantsika). Instead, they clustered with high bootstrap support (86%) in a clade with the single available sequence of *B. bonsi* from Namoroka, a species that is also known to be morphologically similar to *B. decaryi* (see Ramanantsoa 1980; no photograph available). However, the analysis also placed in the same subclade specimens from the Tsingy de Bemaraha (Fig. 5), which morphologically are more reminiscent of *B. brygooi* (Fig. 6).

Our data demonstrate a highly complex situation regarding the taxonomy and evolutionary history of the populations assigned to *B. decaryi* and *B. bonsi* by the phylogenetic analysis. Without additional data it cannot be decided whether the populations forming a clade with *B. bonsi*, i.e. those from Tsingy de Bemaraha and Antsanitia, should best be considered deep conspecific lineages of this species, or might represent new species. The morphological similarity of the Bemaraha specimens with *B. brygooi* may also be explained by a scenario of introgressive hybridisation, and this hypothesis requires testing with nuclear-encoded markers.

On the other hand, independent from the taxonomic conclusions, our data show that the *Brookesia bonsi*/*decaryi* complex occurs beyond the currently known sites, and its extent of

Tab. 1: GenBank accession numbers of DNA sequences of species in the *B. decaryi* group used for phylogenetic analyses. Accession numbers OM885255–OM885270 refer to new sequences obtained in this study.

Species	Voucher	Locality	Accession ND2	Accession ND4
B. aff. *bonsi* A	ACZC 2998	Bemaraha	JX101760	NA
B. aff. *bonsi* A	FGZC 686	Bemaraha	OM885267	NA
B. aff. *bonsi* A	FGZC 739	Bemaraha	OM885268	NA
B. aff. *bonsi* A	FGZC 835	Bemaraha	OM885261	OM885255
B. aff. *bonsi* A	FGZC 945	Bemaraha	OM885262	OM885256
B. aff. *bonsi* A	FGZC 906	Bemaraha	OM885264	OM885258
B. aff. *bonsi* A	ZSM 12/2006 / FGZC 689	Bemaraha	FJ975191	FJ981800
B. aff. *bonsi* B	FGZC 5709	Antsanitia	OM885263	OM885257
B. aff. *bonsi* B	FGZC 5710	Antsanitia	OM885269	NA
B. aff. *bonsi* B	FGZC 5711	Antsanitia	OM885270	NA
B. bonsi	RAX 46	Namoroka	NA	AF443248
B. brunoi	ZSM 888/2010	Anja	JX101754	NA
B. brunoi	ACZC 1934	Anja	JX101757	NA
B. brunoi	ACZC 1924	Anja	JX101758	NA
B. brygooi	ACZC 2569	Isalo	JX101759	NA
B. brygooi	FGZC 5731	Antrema	OM885265	OM885259
B. brygooi	FGZC 5732	Antrema	OM885266	OM885260
B. brygooi	KUZ R61408	Ankarafantsika	FJ975190	FJ981799
B. brygooi	RAX 45	Namoroka	NA	AF443247
B. brygooi	ZFMK 66707	Kirindy	AF448774	FJ981798
B. brygooi	ZSM 563/2001 / FGMV 2001.338	Ankarafantsika	FJ975189	FJ981797
B. decaryi	FGMV 2001.359	Ankarafantsika	FJ975193	FJ981802
B. decaryi	ZSM 558/2001 / FGMV 2001.358	Ankarafantsika	FJ975192	FJ981801
B. perarmata	ZSM 17/2006	Bemaraha	AF448776	FJ981803

occurrence encompasses coastal forests northeast of the Betsiboka river mouth as well as the limestone formations of the Tsingy de Bemaraha. We expect that future fieldwork in these poorly explored dry forest and gallery forest remains might discover additional populations and recommend targeted surveys to determine its coastal distribution in more detail. The example of the highly microendemic *B. brunoi* (Fig. 7), which is only known from a tiny forest remnant in Madagascar's highlands exemplifies that discoveries of *Brookesia* populations can be expected even at sites where only little original habitat is left.

The high genetic diversity within this complex of species detected by our study partly is currently without protection. The coastal forests in the Betsiboka region are rather patchy and degraded, with almost no dry forest left between the coastal forests and Ankarafantsika (Fig. 1), and the Antsanitia forest fragment is currently not included in Madagascar's network of protected areas. The genetically divergent population of leaf chameleons at Antsanitia, which could even represent a new, microendemic species, therefore must be considered to be Critically

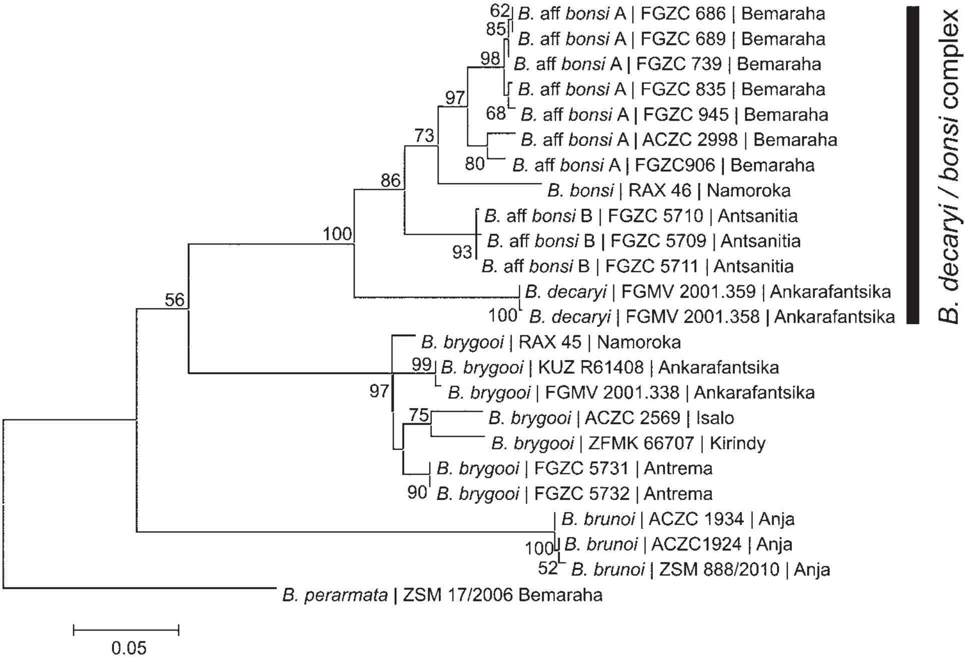

Fig. 3: Maximum Likelihood tree calculated from DNA sequences (1393 bp) from a concatenated alignment of the mitochondrial ND2 and ND4 genes for available samples of the *Brookesia decaryi* group. See Table 1 for details of the sequences used. The tree was calculated with a HKY+G model suggested by the Bayesian Information Criterion implemented in the model finding option of MEGA 7 (Kumar et al., 2016). Numbers at nodes are bootstrap values in percent from 500 replicates (not shown if <50%). *B. perarmata* was defined as the outgroup based on Tolley et al. (2013).

Fig. 4: *Brookesia decaryi* from its type locality, Ankarafantsika National Park. Note the wide body and distinct lateral skin fold. Photo: M. Vences

Fig. 5: *Brookesia* aff. *bonsi* A from Tsingy de Bemaraha National Park. Note that chameleons from this locality are morphologically more similar to *B. brygooi* (Fig. 6) than to *B. decaryi* (Fig. 4). A lateral skin fold is almost not visible. Photo: F. Glaw

Endangered. In order to conserve this population and probably other microendemic components of the fauna and flora at these sites, the remaining coastal forest fragments should be awarded legal protection.

We are indebted to the Malagasy authorities for granting research and export permits (research conducted under permit Nº62/18/MEEF/SG/DGF/DSAP/SCB.Re, specimens exported under CITES permit Nº230C-EA04/MG18) and the German authorities for granting import permits. We are grateful to L. Dwinger, J. Forster, K. Glaw, T. Glaw, P. Wagner, A. Razafimanantsoa and C. Zanotelli for their help with the fieldwork, to A. Laube, T. Negro and MICET for logistic support, to the Malagasy authorities for issuing research and export permits as well as to Global Wildlife Conservation (The Search for Lost Species Initiative) and Carlos Zanotelli (chameleon asset management ag) for funding the expedition in 2018.

Zusammenfassung

Die wenig bekannten madagassischen Stummelschwanzchamäleons *Brookesia decaryi* und *B. bonsi* gelten als eng verwandt und werden auf der Roten Liste der bedrohten Arten der IUCN als „Endangered“ bzw. „Critically Endangered“ eingestuft. Angeregt durch die Entdeckung einer neuen Küstenpopulation von *Brookesia*, die *B. decaryi* morphologisch ähnlich ist, haben wir die genetische Variation des *Brookesia decaryi/B. bonsi*-Komplexes aus West-Madagaskar anhand zweier mitochondrialer Gene untersucht. Unsere phylogenetische Analyse zeigt unerwartete Diskrepanzen zwischen der phylogenetischen Position und der Morphologie der verschiedenen Populationen und weist auf eine komplexe Situation hinsichtlich ihrer Evolutionsgeschichte hin. Unsere Ergebnisse deuten darauf hin, dass der *B. bonsi*-Komplex nicht im Namoroka-Reservat endemisch, sondern im westlichen Madagaskar weit verbreitet ist, und bestätigt, dass *B. decaryi* wahrscheinlich im Ankarafantsika-Nationalpark endemisch ist. Die neu entdeckte Küstenpopula-

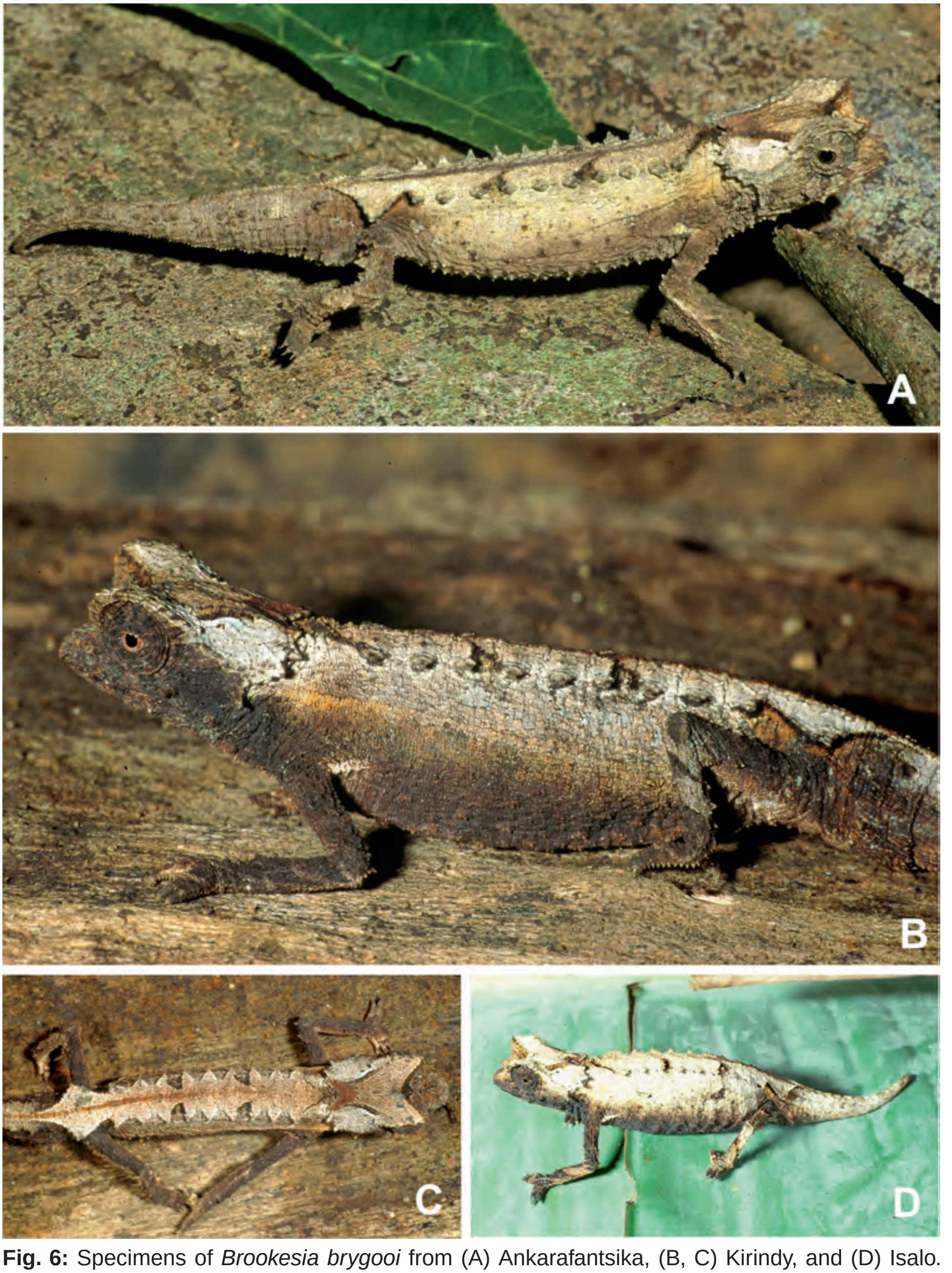

Fig. 6: Specimens of *Brookesia brygooi* from (A) Ankarafantsika, (B, C) Kirindy, and (D) Isalo. Note the weakly expressed lateral skin fold and narrow body shape. Photos A, D: M. Vences, photos B. C: F. Glaw

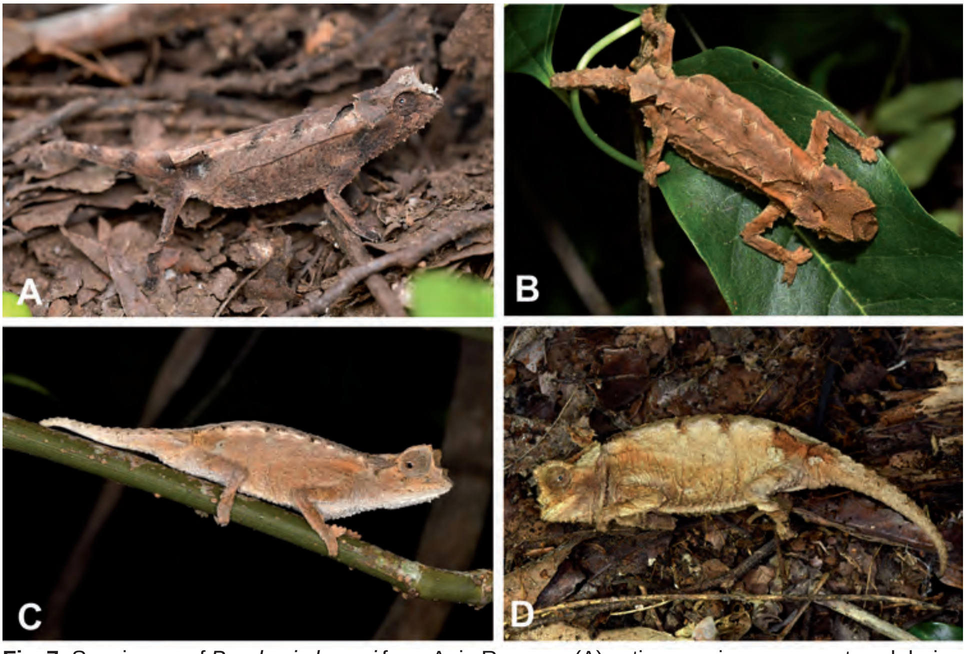

Fig. 7: Specimens of *Brookesia brunoi* from Anja Reserve. (A) active specimen encountered during the day. (B) Sleeping specimen at night, in dorsal view. (C) Specimen in night colouration. (D) Same specimen as in (C), showing death-feigning behaviour after disturbance. Photos: M. Vences

tion ist genetisch verschieden und ihr Lebensraum sollte geschützt werden. Weitere Studien sind erforderlich, um die Taxonomie, die Verbreitung und den Erhaltungsstatus dieses Artenkomplexes zu überprüfen.

References

Belluardo, F., Díaz Quirós, D., Lobón-Rovira, J., Rosa, G.M., Rasoazanany, M., Andreone, F. & Crottini, A. (2021). Uncovering the herpetological diversity of small forest fragments in south-eastern Madagascar (Haute Matsiatra). Zoosystematics and Evolution 97 (2), 315–343.

Bora, P., Randrianantoandro, J.C., Randrianavelona, R., Hantalalaina, E.F., Andriantsimanarilafy, R.R., Rakotondravony, D., Ramilijaona, O.R., Vences, M., Jenkins, R.K.B., Glaw, F. & Köhler, J. (2010). Amphibians and reptiles of the Tsingy de Bemaraha plateau, western Madagascar: checklist, biogeography and conservation. Herpetological Conservation and Biology 5 (1), 111–125.

Carver, E. (2021). 'Unprecedented' fires in Madagascar national park threaten livelihoods and lemurs. Mongabay, available from: https://news.mongabay.com/2021/12/fires-in-madagascar-national-park-threaten-livelihoods-and-lemurs/

Cocca, W., Rosa, G.M., Andreone, F., Aprea, G., Bergò, P.E., Mattioli, F., Mercurio, V., Randrianirina, J.E., Rosado, D., Vences, M. & Crottini, A. (2018). The herpetofauna (Amphibia, Crocodylia, Squamata, Testudines) of the Isalo Massif, Southwest Madagascar: combining morphological, molecular and museum data. Salamandra 54, 178–200.

Crottini, A., Miralles, A., Glaw, F., Harris, D.J., Lima, A. & Vences, M. (2012). Description of a new pygmy chameleon (Chamaeleonidae: *Brookesia*) from central Madagascar. Zootaxa 3490, 63–74.

Glaw, F. & Vences, M. (2007). A Field Guide to the Amphibians and Reptiles of Madagascar. Third Edition. Köln, Vences & Glaw, 496 pp.

Jenkins, R.K.B., Tognelli, M.F., Bowles, P., Cox, N., Brown, J.L., Chan, L., Andreone, F., Andriamazava, A., Andriantsimanarilafy, R.R., Anjeriniaina, M., Bora, P., Brady, L.D., Hantalalaina, E.F., Glaw, F., Griffiths, R.A., Hilton-Taylor, C., Hoffmann, M., Katariya1, V., Rabibisoa, N.H., Rafanomezantsoa, J., Rakotomalala, D., Rakotondravony, H., Rakotondrazafy, N.A., Ralambonirainy, J., Ramanamanjato, J.-B., Randriamahazo, H., Randrianantoandro, J.C., Randrianasolo, H.H., Randrianirina, J.E., Randrianizahana, H., Raselimanana, A.P., Rasolohery, A., Ratsoavina, F.M., Raxworthy, C.J., Robsomanitrandrasana, E., Rollande, F., van Dijk, P.P., Yoder, A.D. & Vences, M. (2014). Extinction risks and the conservation of Madagascar's reptiles. PLoS ONE 9(8): e100173.

Jenkins, R.K.B., Andreone, F., Andriamazava, A., Anjeriniaina, M., Glaw, F., Rabibisoa, N., Rakotomalala, D., Randrianantoandro, J.C., Randrianiriana, J., Randrianizahana, H., Ratsoavina, F. & Robsomanitrandrasana, E. (2011). *Brookesia decaryi*. The IUCN Red List of Threatened Species 2011, e.T172885A6935659. Available from http://dx.doi.org/10.2305/IUCN.UK.2011-2.RLTS.T172885A6935659.en.

Kumar, S., Stecher, G. & Tamura, K. (2016). MEGA7: Molecular Evolutionary Genetics Analysis version 7.0 for bigger datasets. Molecular Biology and Evolution 33, 1870–1874.

Mori, A., Jono, T., Kojima, Y. & Razafimaharatra, B. (2014). A photographic guide to the reptiles and amphibians of Ampijoroa, second edition. Department of Zoology, Kyoto University.

Rakotoarison, A., Erens, J., Ratsoavina, F.M. & Vences, M. (2015). Amphibian and reptile records from around the Betsiboka delta area in North-Western Madagascar. Herpetology Notes 8, 535–543.

Ramanantsoa, G.A. (1980). Description de deux nouvelles espèces de *Brookesia* (Reptilia, Squamata, Chamaeleonidae): *B. legendrei* et *B. bonsi*. Bulletin du Muséum national d'Histoire Naturelle, Paris (4), 1, 685–693.

Raselimanana, A.P. (2008). Herpétofaune des forets sèches malgaches. Malagasy Nature 1, 46–75.

Razafimahatratra, B., Mori, A. & Hasegawa, M. (2008). Sleeping site pattern and sleeping behaviour of *Brookesia decaryi* (Chamaeleonidae) in Ampijoroa dry forest, northwestern Madagascar. Current Herpetology 27, 93–99.

Steffens, T.S., Maheritafika, H.M.R., Hildebrand, J. & Aylward, M. (2020). Lemur distribution and resident attitudes towards forest loss and degradation in Ankarafantsika National Park, Madagascar. Primate Conservation 2020 (34), 61–70.

Tolley, K.A., Townsend, T.M. & Vences, M. (2013). Large-scale phylogeny of chameleons suggests African origins and Eocene diversification. Proceedings of the Royal Society B 280, e20130184.

Vences, M., Miralles, A., Brouillet, S., Ducasse, J., Fedosov, A., Kharchev, V., Kostadinov, I., Kumari, S., Patmanidis, S., Scherz, M.D., Puillandre, N. & Renner, S.S. (2021). iTaxoTools 0.1: Kickstarting a specimen-based software toolkit for taxonomists. Megataxa 6**,** 77–92.

Waeber, P.O., Wilmé, L., Ramamonjisoa, C., Garcia, C., Rakotomalala, D., Rabemananjara, Z.H., Kull, C.A., Ganzhorn, J.U. & Sorg, J.P. (2015). Dry forests in Madagascar: neglected and under pressure. International Forestry Review 17 (S2), 127–148.

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In Memoriam

Dr. Bernhard Christian Blaszkiewitz

17.02.1954 – 16.12.2021

Bernhard Blaszkiewitz. Foto: L. Hemmen

Ohne den enormen Einsatz von Dr. Bernhard Blaszkiewitz würde es heute sicher weder die Ihnen vorliegende Fachzeitschrift „DER ZOOLOGISCHE GARTEN“ noch den Tierpark Berlin mehr geben – insbesondere in den politisch instabilen und unruhigen Zeiten nach dem Mauerfall sorgte er dafür, dass der Tierpark in seiner alten Form und Größe erhalten blieb. Beide, Zeitschrift und Tierpark, zu erhalten, sind dauerhafte und wegweisende Verdienste, die ihm zuzusprechen sind.

Bernhard Blaszkiewitz wurde am 17.02.1954 in Berlin geboren und kannte den Zoo Berlin bereits seit seiner Kindheit. Als einer von vier Brüdern stand sein Berufswunsch bereits mit fünf Jahren fest: Zoodirektor. Und den Weg dorthin ging er zielstrebig. Er studierte Biologe an der Freien Universität Berlin (1974-1978). Parallel suchte er die Praxis und war während des Studiums auch Tierpfleger-Volontär im Berliner Zoo. Nach Stationen im Zoo Frankfurt und Zoo

Gelsenkirchen kam er 1984 als Kurator zurück in den Zoo Berlin. An der Universität Kassel promovierte er 1987. Im Jahre 1991, als ich als Kurator im Kölner Zoo begann, trat er in traditionsreiche und große Fußstapfen – seit dieser Zeit kannten wir uns. Er wurde Nachfolger von Tierparkgründer Prof. Dr. Heinrich Dathe als Direktor des Tierparks Berlin. 2007 übernahm er darüber hinaus auch die Direktion des Zoologischen Gartens Berlins. Dort löste er Dr. Jürgen Lange ab. Damit war er der erste gemeinsame Direktor von Zoo, Tierpark und Aquarium in Personalunion.

Zoo und Tierpark Berlin, die Tiergärtnerei waren sein Leben. Während der über 20-jährigen Amtszeit von Dr. Blaszkiewitz wurden im Tierpark Berlin die zuvor teils nur provisorisch gebauten Stallungen und Anlagen bis zum Jahr 2000 durch Neubauten ersetzt. Es entstanden unter ihm zum Beispiel weitläufige Anlagen für afrikanische Huftiere, Haustiere und Gebirgstiere. Darüber hinaus wurden in seiner Amtszeit das Affenhaus sowie das Giraffenhaus, aber auch die beliebten begehbaren Tieranlagen wie der Vari-Wald, der Streichelzoo und die Känguruanlage gebaut. Die ersten beiden Koalas auf deutschem Boden waren im Tierpark Berlin als Leihgabe aus dem Zoo San Diego (1994) zu sehen, im gleichen Jahr kamen auch die ersten Rundschwanzseekühe in den Tierpark. Im Zoo Berlin eröffnete er 2013 das Vogelhaus und ich nahm damals als Festredner und VdZ-Präsident teil. Weitere tiergärtnerische Höhepunkte waren u. a.: 1991 Europäische Erstzucht Weißlippenhirsch, 1992 Welterstzucht Brillenpelikan oder 2003 Welterstzucht Kampfadler.

Wie kaum ein anderer begeisterte sich Dr. Bernhard Blaszkiewitz für die Vielfalt des Lebens. Er hatte eine umfängliche Bibliothek und weil er auch darin las und sich mit anderen Fachleuten austauschte, große Kenntnisse im Bereich der Tiere und Tiergärtnerei, aber auch darüber hinaus. Zu seinen persönlichen Lieblingstieren gehörten die Dickhäuter – insbesondere Seekühe und Nashörner, ein Kopfabdruck eines Nashorns zierte den Eingang zu seiner Bibliothek. Und er ließ andere von seinem Wissen teilhaben. Über 600 wissenschaftliche und populärwissenschaftliche Veröffentlichungen, inklusive diverser Bücher, flossen in seiner über 40-jährigen Laufbahn als Tiergärtner aus seiner Feder.

Regelmäßig führten ihn Reisen nicht nur in die zoologischen Einrichtungen der Welt oder zu den natürlichen Lebensräumen der Tiere, sondern auch immer wieder ins Heilige Land, war er doch auch ein gläubiger Christ.

Dr. Bernhard Blaszkiewitz war ein Tiergärtner „der alten Schule“. Ein Mann, der Profil hatte und somit auch Kanten und Ecken – so wie die von ihm erbauten Tieranlagen. Er war im wahrsten Sinne des Wortes kein „Kunstfelsfetischist“, wie ein guter Freund einmal sagte. Dass er, früher als erwartet, in den Ruhestand gehen musste, hat ihn damals schwer getroffen – vielleicht hat er sich davon nie erholt.

Für seine Freunde und Mitarbeiter, auch ehemalige, war er – auch im Ruhestand – immer da und seine soziale Verantwortung und Menschlichkeit war vorbildlich. Er war sowohl im deutschen, europäischen als auch im Welt-Zooverband bestens bekannt und vernetzt.

Sein Nachfolger, Dr. Andreas Knieriem, würdigte seine Verdienste wie folgt: „Wir verdanken es unter anderem auch seinem Einsatz, dass wir heute diese zwei herausragenden zoologischen Einrichtungen in unserer Hauptstadt haben, die an Artenvielfalt weltweit ihresgleichen suchen.“ Und der Aufsichtsratsvorsitzende der Zoologischer Garten Berlin AG, Frank Bruckmann, fügte hinzu: „Die Zoologischen Gärten Berlin werden Dr. Bernhard Blaszkiewitz in ehrendem Gedenken behalten. Geleitet von einem festen Wertegefüge, ist er stets unbeirrt seinen Weg gegangen und hat sein Leben in den Dienst der Zoologischen Gärten Berlin gestellt. Im Namen des Aufsichtsrates möchte ich seinen Hinterbliebenen unser aufrichtiges Beileid aussprechen.“

Gerne erinnere ich mich an unsere zahlreichen Begegnungen und Gespräche, sei es mit Wolfgang Gettmann, seinem Otter Nemo und mir, wie wir alle „vier“ durch den Zoo liefen, oder unsere Treffen auf Tagungen oder in einem seiner Tiergärten. Zuletzt sahen wir uns auf der

Feier meines sechzigsten Geburtstages in Köln. Es brauchte nur ein Stichwort und er konnte referieren, insbesondere Ereignisse aus der Tiergärtnerei und Zitate von Kollegen. Er war ein wandelndes Lexikon. Geselligkeit bei gutem Essen und Getränken, seine Leibesfülle ließ es stets erahnen, waren ihm wichtig. Auf seinem Begräbnis, wo leider nicht viele die Gelegenheit hatten, sich von ihm zu verabschieden, sprach ein Pastor, ein Freund und Wegbegleiter, über ihn als Freund, Christ und Tiergärtner. Die Rede war, für alle, die Bernhard nahe standen und kannten, berührend – ihr Inhalt, sowie ein junger Fuchs, der den Trauerzug fast bis zu seiner Ruhestätte, begleitete, hätten Bernhards Herz, dass so groß, aber auch so krank war, sehr erfreut. Dr. Blaszkiewitz verstarb plötzlich und für viele unerwartet am 16. Dezember 2021 in seiner Berliner Wohnung. Sein Wissen, seine Geradlinigkeit, seinen Humor und seine Freundschaft werden wir vermissen

Theo Pagel, Köln

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