

Malagasy birds in zoological gardens – an analysis of zoo databases as basis for improved ex situ conservation measures

Madagassische Vögel in Zoologischen Gärten – Zoodatenbankanalysen als Grundlage für verbesserten ex-situ-Artenschutz

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Abstract

We investigated for which threatened endemic Malagasy bird species zoo populations already exist, and which threatened species are not yet covered by ex situ conservation measures. To gain an overview of Malagasy bird species held in zoos, the number of individuals kept, the number of keeping institutions and successful reproduction within the last 12 months were analysed based on collection information from ZIMS database (Species360, Bloomington, MN, USA), supplemented with data from ZTL (List of Zoo Animals: <https://zootierliste.de/>). Of the 195 Malagasy bird species, 142 occur exclusively in the Malagasy region, comprising Madagascar and surrounding islands, and 117 are endemic to Madagascar. Currently, 28 (24%) of the endemic Malagasy bird species are evaluated as threatened, of which two are Critically Endangered, 11 Endangered and 15 Vulnerable according to IUCN. A total of 131 institutions worldwide kept at least one of the 15 endemic Malagasy bird species held. Three of the fifteen endemic Malagasy bird species held are threatened, of which one is Critically Endangered and two are Endangered according to IUCN. Thus, according to our analysis 25 (89%) of the 28 threatened endemic Malagasy bird species are not covered by ex situ populations. According to ZIMS database, a total of eight of the fifteen endemic Malagasy bird species kept in zoos worldwide had successfully reproduced within the last

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12 months, with three of them being threatened. A richness analysis, which was performed to find out how zoos keeping Malagasy birds are distributed in a global scale, revealed that current zoo collections of threatened endemic Malagasy bird species are mainly concentrated in Europe and North America. A protected area coverage analysis, viz. a comparison of the distribution of protected areas with localities of endemic and threatened endemic species, showed that the existing protected area system does not provide enough coverage for several threatened endemic species. We have made recommendations for the shift from non-threatened species such as *Bubulcus ibis* to threatened species such as *Ardeola idae*. Species from endemic families should be the focus of new ex situ husbandry and the keeping of Critically Endangered species should be included (e.g., *Haliaeetus vociferoides*) or expanded (e.g., *Aythya innotata*). For these species, experience from past husbandry, both positive and negative, or experience from the keeping of closely related species is available. Our findings thus can be used as a guideline to improve zoo collections and to expand the conservation breeding network for threatened endemic Malagasy birds which is in accordance with the One Plan Approach proposed by the IUCN SSC Conservation Planning Specialist Group (CPSG).

Keywords: Aves, conservation breeding, Madagascar, One Plan Approach, richness analysis, ZIMS review, zoo biology

1. Introduction

The Malagasy region, viz. the Paleotropical subregion Madagassis, comprises Madagascar, the archipelagos of the Seychelles, Comoros and Mascarene Islands and six other smaller and more isolated islands (Martin et al., 2000). A land mass consisting of today's Madagascar, the Seychelles and India split off from the Gondwana continent 160 to 158 million years ago. Madagascar isolated from India and the Seychelles 84–96 million years ago (Briggs, 2003).

Madagascar lies off the east coast of Africa, with the Mozambique Channel in between, which is 340 km wide at its narrowest point. The mountains in the east and in the centre of Madagascar are of volcanic origin and some are 88 million years old. The west and south of Madagascar emerged from sedimentation and are of more recent origin. Most rivers have their source in the eastern mountains and then flow westwards towards the Mozambique Channel (Kent, 2021). The largest lakes are Alaotra (22,000 ha), Kikony (10,000 ha) and Ihotry (6,800 ha) (Hawkins et al., 2015).

Madagascar is a hotspot of biodiversity, with nearly 90% of its species being endemic (Myers et al., 2000; Ganzhorn et al., 2001; Goodman & Benstead, 2003; Goodman, 2005; Campbell, 2016). This endemism is not only reflected at the species and genus level but also at the family level. For example, there are eight plant families, six bird families and five primate families, which are endemic to the island (Dewar, 2007).

Only a fifth of Madagascar is still covered by primary forest. This primary forest is made up of almost half the rainforest, one third from the western dry forest and one sixth from the southern thorn forest (Harper, 2007). The primary rainforest in the east is the habitat of most birds, with 44 endemic species, most of which only occur in the rainforest. It covers an area of 47,000 km². The western dry forest has an area of 32,000 km² and is home to a total of 172 bird species, nine of which are endemic. In total 159 species of birds are found in the southern thorn forest, 10 of which are endemic (Hawkins et al., 2015).

Seven bird genera with total 24 species can only be found in the Malagasy region, which is home for more than 180 bird species. More than 110 bird species are endemic to this region (Hawkins et al., 2015). Madagascar's bird diversity generally evolved in two ways, either through adaptive radiation or via multiple immigration (Yamagishi, 2001), which eventually resulted in

aforementioned six endemic bird families: the Malagasy warblers (Bernieridae), ground rollers (Brachypteraciidae), cuckoo rollers (Leptosomidae), mesites (Mesitornithidae), asities (Philepittidae) and the vangas (Vangidae), containing a total of 45 species. Another ten genera with a total of 21 bird species are endemic to Madagascar, and there are 31 subspecies of birds found in Madagascar. In total, 117 bird species are endemic to Madagascar (Hawkins et al., 2015).

However, Madagascar's biodiversity is threatened by the ongoing loss of natural habitat. The annual rate for the loss of diversity and habitat is currently 4.4% (Morelli, 2020; DPZ, 2021). The primary rainforest continues to be degraded, 90% of the entire primary forest has already been lost (Harper, 2007). In recent years in particular the discovery of gemstone sources in the north-east of the island has led to extensive deforestation (Garbutt, 2020). Today, 24% of all birds in Madagascar are listed as threatened on the Red List of the International Union for Conservation of Nature and Natural Resources (IUCN). The birds of the rainforest and wetlands are particularly affected (Garbutt, 2000).

We are in the sixth mass extinction, which is human-induced (Ceballos et al., 2015). There is an urgent need to improve species and habitat protection. The "One Plan Approach" of the Conservation Planning Specialist Group (CPSG) of the IUCN combines two historically mostly separately treated approaches: the protection of wild populations and their habitats on the one hand (in situ), and conservation through zoo breeding programmes on the other (ex situ) (CPSG, 2021), with the aim to create a global population conservation management system (Wyard, 2020).

The omnipresent trend that more and more habitats in Madagascar are being destroyed shows the urgency of ex situ measures in addition to in situ species protection. At the current rate of natural destruction, the eastern rainforest would be cleared in 2080 (Morelli, 2020). Establishing protected areas alone is currently insufficient and still too slow to save many species from extinction. In addition to, for example, resettlement programmes and hunting restrictions, the conservation of metapopulations must be considered, one of the main tasks of zoos (Conde et al., 2013). By implementation of ex situ measures, viz. to keep a threatened species under human care in the frame of a conservation breeding programme, that species can be saved from extinction and later be released into secure and protected habitats, as it was the case for the Californian condor (Cohn, 1999).

In order to act strategically and prioritise, analyses should be carried out to determine which species are already kept and which of these are successfully reproducing (Conde et al., 2013). The Zoological Information Management Software (ZIMS) supplies the data for such analyses (e.g., Garcia et al., 2008; Ziegler et al., 2016, 2017). It then can also be determined, how many threatened species are already secured in zoos, as was just recently performed by Leiss et al. (2021) for threatened Malagasy freshwater fishes in zoos and aquaria and by Ziegler et al. (2022) for threatened Malagasy amphibians and reptiles in zoos which highlighted the necessity of an improved ex situ conservation network. By applying additional richness analyses, clusters of husbandry can be uncovered to identify collection gaps and improving aforementioned conservation breeding networks, as was recently performed by Jacken et al. (2020) and Wahle et al. (2021) for threatened amphibians and skinks in a global scale.

According to Conde et al. (2013), the proportion of threatened bird species kept in captivity globally, viz. birds listed as Vulnerable, Endangered or Critically Endangered by IUCN (2021), is currently 8% worldwide. It was the aim of this study to investigate for which threatened endemic Malagasy bird species ex situ populations already exist and which threatened species are not yet covered by ex situ conservation measures, based on ZIMS (Species360, Bloomington, MN, USA) and List of Zoo Animals (ZTL) database analyses. We also performed a richness analysis to assess how zoos keeping Malagasy birds are distributed in a global scale and which degree of species diversity they cover, as well as a protected area coverage analysis, viz. a comparison of the distribution of protected areas with localities of endemic and threatened endemic species.

2. Material and Methods

2.1. Species list and distribution

A list of Malagasy bird species was compiled on the basis of the field guide by Hawkins et al. (2015) and the online database Avibase (2021a). The classification is up to date as of April 2021 and is based on the Avibase taxonomy (2021a). Compared with data from the database from BirdLife, there existed three differences: The non-threatened species *Asio madagascariensis* is added therein and the non-threatened species *Otus madagascariensis* and *Porphyrio madagascariensis* are listed as subspecies of *Otus rutilus* and *Porphyrio porphyrio*, respectively (BirdLife, 2022). The bird species were classified according to their distribution. A distinction was made between species that occur in Africa and the Malagasy region, species that can be found on Madagascar and surrounding islands (e.g., Reunion, Comoros, Mayotte) and species that are endemic to Madagascar. In case of contradicting distribution information, the IUCN Red List (IUCN, 2012) was consulted.

2.2. Conservation status analysis

Conservation status and population trend followed the IUCN Red List (2022). The following categories were considered, with increasing risk: DD (Data Deficient), LC (Least Concern), NT (Near Threatened), VU (Vulnerable), EN (Endangered), CR (Critically Endangered), EW (Extinct in the Wild) (IUCN, 2012). The term “threatened” relates to species with the threat categories CR, EN or VU.

2.3. ZIMS analysis

The global collections of Malagasy bird species were analysed based on the ZIMS database (<https://zims.species360.org>) provided by the Species360 organisation (ZIMS, 2021). ZIMS (Zoological Information Management Software) is maintained by Species360 members and now contains data on 22,000 species worldwide. ZIMS is a global database that can be accessed by zoos, aquariums and other institutions. The main purpose of ZIMS is to determine the extent of animal populations in zoos worldwide, to document animal transactions and to show relationships of individual animals. By now, more than 1100 zoos are connected to ZIMS as Species360 members. Species360 is used by more than 40 associations, more than 50 conservation organisations and at more than 20 universities (Species360, 2021). For EAZA (European Association of Zoos and Aquaria) members data entry is obligatory, but other institutions do it voluntarily. Hence, it is always possible that at ZIMS not all species and individuals kept in zoos are recorded.

To gain an overview of Malagasy bird species held in zoos, according to Leiss et al. (2021) and Ziegler et al. (2022), the number of individuals kept, the number of keeping institutions and successful reproduction within the last 12 months were analysed based on collection information from ZIMS database. The ZIMS analysis was performed on May 12, 2021. If there was no current record, it was determined whether animals had been kept previously. For that purpose, the date January 01, 1860 was chosen because numerous zoological gardens were opened in the 1860s (Dittrich, 2004). In some cases there was no species folder generated in ZIMS, so older scientific names (synonyms) were asked if the first query did not result in a match (Avibase, 2021b). The ZIMS list may miss some zoo populations or breeding records, as some data may be obsolete or have not (yet) been entered in the database, and some zoos do not use ZIMS yet.

2.4. List of Zoo Animals (ZTL) analysis

To increase the coverage of our data set, following Leiss et al. (2021) and Ziegler et al. (2022), we additionally cross-checked the ZIMS data on May 12, 2021 with species collections for further institutions in Germany and Europe recovered from the website “Zootierliste” (ZTL, List of Zoo Animals: <https://zootierliste.de/>). ZTL includes collections of additional institutions as well as some private zoos, rescue centres and other facilities (Graf et al., 2020). The zoo animal list is an online database that is maintained and kept up to date by zoo employees and private individuals. It includes information on all vertebrate classes and species that were previously and are currently kept in European zoos. Keeping times and gender ratios are also provided. However, it is only as up to date as the entries made by the members. ZTL data were only analysed in our overall summary of species present in institutions. If ZIMS / ZTL analyses revealed to be unsuccessful, a note was made: “Not in ZIMS / ZTL.”

2.5. Richness analysis

A richness analysis was performed with R (R Core Team, 2021) in order to identify patterns in the keeping of Malagasy birds. Therefore, the coordinates of the zoos keeping Malagasy bird species were retrieved from ZIMS on May 12, 2021 (ZIMS, 2021). In this analysis, Australia included Australia and Oceania. Based on the number of individuals per species kept in each zoo, we computed the total number of zoos keeping Malagasy birds per country as well as the following biodiversity indices using the package *vegan* (Oksanen et al., 2020): the Shannon-Weaver Index ($H = -\sum p_i \log(b) p_i$), Pielou’s evenness ($J = H/\log(n)$), with n representing the total number of species, 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 represents the natural logarithm ($b=2$ herein) (Zeleny, 2022).

2.6. Protected area coverage analysis

The distribution maps for the protected area coverage analysis were compiled by BirdLife International (2022). The data of the protected areas (PAs) of Madagascar were downloaded from UNEP-WCMC and IUCN (2022). The Ecoregions of the world were taken from Olsen et al. (2001). The analysis was performed using the programme R and the packages “raster” (Hijmans et al. 2022), “shapefiles” (Stabler, 2013) and “redlist” (Chamberlain et al., 2020). The Malagasy bird species were joined in a table with their habitats and an estimation whether those are suitable, the PAs they inhabit, their IUCN threat status and criteria. As baseline for available habitats we used the level 2 products provided by Jung et al. (2020). It was analysed which species each single PA contains, how many in total and how many threatened species. Species richness analyses with grid cell sizes of 100 x 100 m were made to compare the distribution of protected areas with localities of endemic and threatened endemic species.

We also explored the impact of varying grid-cell size on two endemism indices proposed by Crisp et al. (2001): weighted endemism (WE) and corrected weighted endemism (CWE). WE measures endemism by inversely weighting the proportion of endemics by their range size, so that species with smaller range sizes weight more than those with large ranges. To obtain the CWE this value is then divided by the local species richness (Brown et al., 2016).



Fig. 1: Bird species from some endemic families: top left *Monias benschi* (Mesithornitidae); top right *Uratelornis chimaera* (Brachypteraciidae), bottom left *Philepitta schlegeli* (Philepittidae) and bottom right *Xenopirostris damii* (Vangidae). Photos: M. Vences (top left), T. Pagel (top right) and B. Marcordes (bottom)

3. Results

3.1. Bird species diversity and conservation

More than 300 bird species are reported to occur in Madagascar (Avibase, 2021a). Migratory birds that can only be found temporarily or migrating in Madagascar were not analysed. A total of 195 bird species was recorded in the analysis. Of these 195 bird species, 53 species likewise were found in Africa and the Malagasy region (27%). 142 of the 195 bird species were found

in Madagascar and the surrounding islands (73%) (Tab. 1). 117 of the 142 bird species were endemic to Madagascar (82%), with the remaining 25 of them (18%) also occurring on the surrounding islands (e.g., Comoros, Seychelles, Mayotte) (Fig. 2; Tab.1).

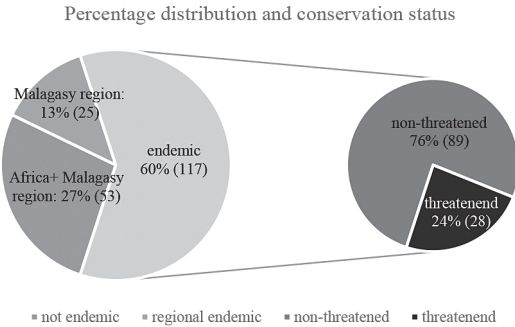


Fig. 2: Percentage distribution of analysed bird species and percentage conservation status to endemic bird species of Madagascar.

Tab. 1: Bird species with distribution on Madagascar and surrounding islands, including distribution (M = Madagascar, MR = Madagascar + surrounding islands), IUCN category and number of locations (IUCN, 2021), date of last survey and population trends; threatened species are highlight- ed shaded. 28 of the 117 endemic bird species of Madagascar (Tab. 1) were threatened (24%) according to the Red List: 2 Critically Endangered, 11 Endangered, 15 Vulnerable (IUCN, 2021).

| | Distribution | IUCN category | Number of locations (IUCN 2021) | Last survey | Population trend |
|-------------------------------------|--------------|---------------|---------------------------------|-------------|------------------|
| Family Accipitridae | | | | | |
| <i>Accipiter francesiae</i> | MR | LC | | 2016 | stable |
| <i>Accipiter henstii</i> | M | NT | | 2020 | decreasing |
| <i>Accipiter madagascariensis</i> | M | NT | | 2018 | decreasing |
| <i>Aviceda madagascariensis</i> | M | LC | | 2016 | decreasing |
| <i>Buteo brachypterus</i> | M | LC | | 2016 | stable |
| <i>Circus macroscleus</i> | MR | EN | 11-100 | 2016 | decreasing |
| <i>Eutriorchis astur</i> | M | EN | 11-100 | 2016 | decreasing |
| <i>Haliaeetus vociferoides</i> | M | CR | 11-100 | 2016 | decreasing |
| <i>Polyboroides radiatus</i> | M | LC | | 2016 | stable |
| Family Acrocephalidae | | | | | |
| <i>Acrocephalus newtoni</i> | M | LC | | 2016 | stable |
| <i>Nesillas lantzii</i> | M | LC | | 2016 | stable |
| <i>Nesillas typica</i> | MR | LC | | 2016 | stable |
| Family Alaudidae | | | | | |
| <i>Eremopterix hova</i> | M | LC | | 2016 | increasing |
| Family Alcedinidae | | | | | |
| <i>Corythornis madagascariensis</i> | M | LC | | 2016 | decreasing |
| <i>Corythornis vintsioides</i> | MR | LC | | 2016 | stable |
| Family Anatidae | | | | | |
| <i>Anas bernieri</i> | M | EN | 11-100 | 2016 | decreasing |
| <i>Anas melleri</i> | M | EN | 11-100 | 2016 | decreasing |
| <i>Aythya innotata</i> | M | CR | 1 | 2016 | stable |

Tab. 1: Continued.

| | Distribution | IUCN category | Number of locations (IUCN 2021) | Last survey | Population trend |
|---------------------------------------|--------------|---------------|------------------------------------|----------------|------------------|
| Family Apodidae | | | | | |
| <i>Zoonavena grandidieri</i> | M | LC | | 2018 | decreasing |
| Family Ardeidae | | | | | |
| <i>Ardea humbloti</i> | MR | EN | 11-100 | 2016 | decreasing |
| <i>Ardeola idae</i> | MR | EN | | 2016 | decreasing |
| Family Bernieridae | | | | | |
| <i>Bernieria madagascariensis</i> | M | LC | | 2016 | decreasing |
| <i>Crossleyia tenebrosa</i> | M | DD | | 2020 | decreasing |
| <i>Crossleyia xanthophrys</i> | M | NT | | 2016 | decreasing |
| <i>Cryptosylvicola randrianasoloi</i> | M | LC | | 2016 | decreasing |
| <i>Hartertula flavoviridis</i> | M | NT | | 2016 | decreasing |
| <i>Oxylabes madagascariensis</i> | M | LC | | 2016 | decreasing |
| <i>Randia pseudozosterops</i> | M | LC | | 2016 | decreasing |
| <i>Thamnornis chloropetoides</i> | M | LC | | 2016 | decreasing |
| <i>Xanthomixis apperti</i> | M | VU | 4 | 2016 | stable |
| <i>Xanthomixis cinereiceps</i> | M | NT | | 2016 | decreasing |
| <i>Xanthomixis zosterops</i> | M | LC | | 2016 | decreasing |
| Family Brachypteraciidae | | | | | |
| <i>Atelornis crossleyi</i> | M | NT | | 2016 | decreasing |
| <i>Atelornis pittoides</i> | M | LC | | 2016 | stable |
| <i>Brachypteracias leptosomus</i> | M | VU | 11-100 | 2016 | decreasing |
| <i>Geobiasies squamiger</i> | M | VU | 11-100 | 2016 | decreasing |
| <i>Uratelornis chimaera</i> | M | VU | 11-100 | 2016 | decreasing |
| Family Campephagidae | | | | | |
| <i>Cebilepyris cinereus</i> | M | LC | | 2016 | decreasing |
| Family Caprimulgidae | | | | | |
| <i>Caprimulgus madagascariensis</i> | MR | LC | | 2016 | stable |
| <i>Gactornis enarratus</i> | M | LC | | 2016 | decreasing |
| Family Charadriidae | | | | | |
| <i>Charadrius bifrontatus</i> | M | LC | | 2016 | unknown |
| <i>Charadrius thoracicus</i> | M | VU | | 2016 | decreasing |
| Family Cisticolidae | | | | | |
| <i>Cisticola cherina</i> | MR | LC | | 2016 | stable |
| <i>Neomixis pallidior</i> | M | LC | | 2016 | unknown |
| <i>Neomixis striatigula</i> | M | LC | | 2016 | unknown |
| <i>Neomixis tenella</i> | M | LC | | 2016 | stable |
| <i>Neomixis viridis</i> | M | LC | | 2016 | decreasing |
| Family Columbidae | | | | | |
| <i>Alectroenas madagascariensis</i> | M | LC | | 2016 | decreasing |
| <i>Nesoenas picturatus</i> | MR | LC | | 2016 | stable |
| <i>Treron australis</i> | MR | LC | | 2016 | decreasing |
| Family Cuculidae | | | | | |
| <i>Centropus toulou</i> | MR | LC | | 2018 | decreasing |
| <i>Coua caerulea</i> | M | LC | | 2018 | decreasing |
| <i>Coua coquereli</i> | M | LC | | 2018 | decreasing |
| <i>Coua cristata</i> | M | LC | | 2016 | decreasing |
| <i>Coua cursor</i> | M | LC | | 2018 | decreasing |
| <i>Coua gigas</i> | M | LC | | 2016 | decreasing |
| <i>Coua olivaceiceps</i> | M | LC | | 2016 | stable |

Tab. 1: Continued.

| | Distribution | IUCN category | Number of locations (IUCN 2021) | Last survey | Population trend |
|-----------------------------------|--------------|---------------|------------------------------------|----------------|------------------|
| <i>Coua pyropyga</i> | M | LC | | 2016 | decreasing |
| <i>Coua reynaudii</i> | M | LC | | 2018 | decreasing |
| <i>Coua ruficeps</i> | M | LC | | 2016 | stable |
| <i>Coua serriana</i> | M | LC | | 2018 | decreasing |
| <i>Coua verreauxi</i> | M | LC | | 2017 | decreasing |
| <i>Cuculus rochii</i> | M | LC | | 2016 | stable |
| Family Dicruridae | | | | | |
| <i>Dicrurus forficatus</i> | MR | LC | | 2016 | unknown |
| Family Estrildidae | | | | | |
| <i>Lonchura nana</i> | M | LC | | 2016 | stable |
| Family Falconidae | | | | | |
| <i>Falco newtoni</i> | MR | LC | | 2016 | increasing |
| <i>Falco zoniventris</i> | M | LC | | 2016 | stable |
| Family Glareolidae | | | | | |
| <i>Glareola ocularis</i> | M | VU | 11-100 | 2016 | decreasing |
| Family Hirundinidae | | | | | |
| <i>Riparia cowani</i> | M | LC | | 2016 | decreasing |
| Family Jacanidae | | | | | |
| <i>Actophilornis albinucha</i> | M | EN | | 2020 | decreasing |
| Family Leptosomidae | | | | | |
| <i>Leptosomus discolor</i> | MR | LC | | 2016 | decreasing |
| Family Locustellidae | | | | | |
| <i>Bradypterus brunneus</i> | M | LC | | 2016 | decreasing |
| <i>Bradypterus seebohmi</i> | M | LC | | 2016 | decreasing |
| Family Mesitornithidae | | | | | |
| <i>Mesitornis unicolor</i> | M | VU | 11-100 | 2018 | decreasing |
| <i>Mesitornis variegatus</i> | M | VU | 6 | 2018 | decreasing |
| <i>Monias benschi</i> | M | VU | 11-100 | 2016 | decreasing |
| Family Monarchidae | | | | | |
| <i>Terpsiphone mutata</i> | MR | LC | | 2016 | decreasing |
| Family Motacillidae | | | | | |
| <i>Motacilla flaviventris</i> | M | LC | | 2016 | stable |
| Family Musciacipidae | | | | | |
| <i>Copsychus albospectus</i> | M | LC | | 2016 | decreasing |
| <i>Copsychus pica</i> | M | LC | | 2016 | decreasing |
| <i>Monticola erythronotus</i> | M | EN | 1 | 2016 | decreasing |
| <i>Monticola imerina</i> | M | LC | | 2016 | stable |
| <i>Monticola sharpei</i> | M | LC | | 2016 | decreasing |
| <i>Saxicola torquatus</i> | MR | LC | | 2020 | stable |
| Family Nectariniidae | | | | | |
| <i>Cinnyris notatus</i> | MR | LC | | 2016 | stable |
| <i>Cinnyris sovimanga</i> | MR | LC | | 2016 | stable |
| Family Phasianidae | | | | | |
| <i>Margaroperdix madagarensis</i> | M | LC | | 2018 | decreasing |
| Family Philepittidae | | | | | |
| <i>Neodrepanis coruscans</i> | M | LC | | 2018 | decreasing |
| <i>Neodrepanis hypoxantha</i> | M | VU | 11-100 | 2017 | decreasing |
| <i>Philepitta castanea</i> | M | LC | | 2018 | decreasing |
| <i>Philepitta schlegeli</i> | M | NT | | 2016 | decreasing |

Tab. 1: Continued.

| | Distribution | IUCN category | Number of locations (IUCN 2021) | Last survey | Population trend |
|-------------------------------------|--------------|---------------|------------------------------------|----------------|------------------|
| Family Ploceidae | | | | | |
| <i>Foudia madagascariensis</i> | M | LC | | 2018 | stable |
| <i>Foudia omissa</i> | M | LC | | 2018 | decreasing |
| <i>Ploceus nelicourvi</i> | M | LC | | 2018 | stable |
| <i>Ploceus sakalava</i> | M | LC | | 2016 | stable |
| Family Podicipedidae | | | | | |
| <i>Tachybaptus pelzelinii</i> | M | EN | 11-100 | 2018 | decreasing |
| Family Psittaculidae | | | | | |
| <i>Agapornis canus</i> | M | LC | | 2018 | stable |
| <i>Coracopsis nigra</i> | MR | LC | | 2016 | stable |
| <i>Coracopsis vasa</i> | MR | LC | | 2018 | decreasing |
| Family Pteroclididae | | | | | |
| <i>Pterocles personatus</i> | M | LC | | 2016 | stable |
| Family Pycnonotidae | | | | | |
| <i>Hypsipetes madagascariensis</i> | MR | LC | | 2018 | stable |
| Family Rallidae | | | | | |
| <i>Dryolimnas cuvieri</i> | MR | LC | | 2016 | stable |
| <i>Porphyrio madagascariensis</i> | M | LC | | NA | NA |
| <i>Rallus madagascariensis</i> | M | VU | | 2020 | decreasing |
| <i>Zapornia olivieri</i> | M | EN | 6-10 | 2016 | decreasing |
| Family Sarothruridae | | | | | |
| <i>Mentocrex beankaensis</i> | M | NT | | 2016 | decreasing |
| <i>Mentocrex kioloides</i> | M | LC | | 2016 | decreasing |
| <i>Sarothrura insularis</i> | M | LC | | 2016 | stable |
| <i>Sarothrura watersi</i> | M | EN | 3 | 2016 | decreasing |
| Family Scolopacidae | | | | | |
| <i>Gallinago macrodactyla</i> | M | VU | | 2021 | decreasing |
| Family Strigidae | | | | | |
| <i>Asio capensis</i> | M | LC | | 2016 | stable |
| <i>Athene superciliiaris</i> | M | LC | | 2016 | decreasing |
| <i>Otus madagascariensis</i> | M | NA | | NA | NA |
| <i>Otus rutilus</i> | M | LC | | 2016 | stable |
| Family Sturnidae | | | | | |
| <i>Hartlaubius auratus</i> | M | LC | | 2018 | decreasing |
| Family Threskiornithidae | | | | | |
| <i>Lophotibis cristata</i> | M | NT | | 2016 | decreasing |
| <i>Threskiornis bernieri</i> | MR | EN | | 2021 | decreasing |
| Family Turnicidae | | | | | |
| <i>Turnix nigricollis</i> | M | LC | | 2016 | stable |
| Family Tytonidae | | | | | |
| <i>Tyto soumagnei</i> | M | VU | 11-100 | 2016 | decreasing |
| Family Upupidae | | | | | |
| <i>Upupa marginata</i> | M | LC | | 2016 | stable |
| Family Vangidae | | | | | |
| <i>Artamella viridis</i> | M | LC | | 2016 | unknown |
| <i>Calicalicus madagascariensis</i> | M | LC | | 2016 | unknown |
| <i>Calicalicus rufocarpalis</i> | M | VU | 11-100 | 2016 | stable |
| <i>Cyanolanius madagascarinus</i> | MR | LC | | 2016 | unknown |
| <i>Euryceros prevostii</i> | M | EN | 11-100 | 2018 | decreasing |

Tab. 1: Continued.

| | Distribution | IUCN category | Number of locations (IUCN 2021) | Last survey | Population trend |
|------------------------------------|--------------|---------------|------------------------------------|----------------|------------------|
| <i>Falcula palliata</i> | M | LC | | 2016 | unknown |
| <i>Hypositta corallirostris</i> | M | LC | | 2016 | unknown |
| <i>Leptopterus chabert</i> | M | LC | | 2016 | unknown |
| <i>Mystacornis crossleyi</i> | M | LC | | 2016 | unknown |
| <i>Newtonia amphichroa</i> | M | LC | | 2020 | unknown |
| <i>Newtonia archboldi</i> | M | LC | | 2016 | unknown |
| <i>Newtonia brunneicauda</i> | M | LC | | 2016 | unknown |
| <i>Newtonia fanovanae</i> | M | VU | 11-100 | 2016 | decreasing |
| <i>Oriolia bernieri</i> | M | EN | 11-100 | 2018 | decreasing |
| <i>Pseudobias wardi</i> | M | LC | | 2016 | unknown |
| Family Vangidae | | | | | |
| <i>Schetba rufa</i> | M | LC | | 2016 | unknown |
| <i>Tylas eduardi</i> | M | LC | | 2016 | unknown |
| <i>Vanga curvirostris</i> | M | LC | | 2016 | unknown |
| <i>Xenopirostris damii</i> | M | EN | 2 | 2016 | decreasing |
| <i>Xenopirostris polleni</i> | M | NT | | 2016 | unknown |
| <i>Xenopirostris xenopirostris</i> | M | LC | | 2016 | unknown |
| Family Zosteropidae | | | | | |
| <i>Zosterops maderaspatanus</i> | MR | LC | | 2018 | decreasing |



Fig. 3: Two Endangered bird species: *Ardeola idae* (left) and *Threskiornis bernieri* (right) in their natural habitat in Madagascar. Photos: B. Marcordes

The Critically Endangered Madagascar pochard (*Aythya innotata*) is known from only a single lake and the Endangered Amber Mountain rock thrush (*Monticola erythronotus*) is likewise known from only a single site. The Endangered Van Dam’s vanga (*Xenopirostris damii*), the Endangered slender-billed flufftail (*Sarothrura watersi*), the Vulnerable Appert’s tetraka (*Xanthomixis apperti*), the Vulnerable white-breasted mesite (*Mesitornis variegatus*) and the Endangered sakalava rail (*Zapornia olivieri*) are known only from few (2-10) sites on Madagascar. For one Endangered and three Vulnerable endemic bird species of Madagascar no site information was provided (Tab. 1) (IUCN, 2021).

The 89 endemic bird species of Madagascar that were not listed as threatened belonged to the categories of Least Concern (77), Near Threatened (10), Data Deficient (1) and Not Evaluated (1) (IUCN, 2021) (Fig. 4).

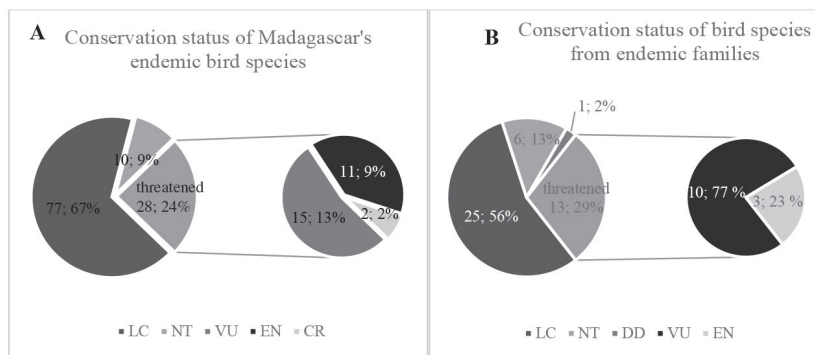


Fig. 4: Red List status (IUCN 2021) of endemic bird species of Madagascar (A) and species from endemic bird families of Madagascar (B).

Within the six endemic Malagasy bird families, the mesites (Mesitornithidae), ground rollers (Brachypteraciidae), curols (Leptosomidae), asities (Philepittidae), tetrakas (Bernieridae) and vangas (Vangidae), 13 (29%) of the in total 45 species are Red-Listed as threatened (Tab. 1): 3 Endangered (23%) and ten Vulnerable (77%) (Fig. 4). Hence, three of the 11 Endangered endemic bird species of Madagascar (27%) and 10 of the 15 Vulnerable endemic bird species of Madagascar (66.6%) derive from an endemic bird family of this island.

3.2. Population trends of the endemic bird species of Madagascar

Of the 117 endemic bird species of Madagascar, 70 had declining populations (18 unknown, 26 stable, 1 increasing, 2 no trend). The population sizes of 89 of Madagascar's 117 endemic bird species were from 2016, with all remaining population sizes from years thereafter (IUCN, 2021). The Critically Endangered Madagascar porchard (*Aythya innotata*), the Vulnerable Appert's tetraka (*Xanthomixis apperti*) and the Vulnerable red-shouldered vanga (*Calicalicus rufoarpalis*) had stable populations. 25 of 28 threatened endemic bird species showed declining populations (Tab. 1).

3.3. ZIMS and ZTL analysis

Zoo collections of Madagascar's endemic bird species based on ZIMS and ZTL

Of the in total 117 endemic bird species of Madagascar, 81 species were recorded only in ZIMS, 27 species were listed both in ZIMS and ZTL, two species were recorded only in ZTL and eight species were not included in the zoo databases. The endemic Malagasy bird species recorded in ZTL only, *Foudia omissa*, was only held in the past and no animals could be identified by ZIMS and ZTL. Thus, only the endemic Malagasy bird species included in ZIMS were further analysed.

3.4. Endemic Malagasy bird species kept in zoos worldwide

Of the 107 endemic Malagasy bird species, in total 16 species (14%) are held in zoos: three threatened and 13 non-threatened species (ZIMS, 2021). In other words, of the 107 endemic

Malagasy bird species, 25 threatened and 66 non-threatened species are not yet represented in zoos according to this analysis.

The analysis revealed a total of 1769 individuals held in zoos. 505 of them belonged to threatened taxa (29%) (Fig. 5). All threatened endemic Malagasy bird species were kept in zoo populations consisting of more than 100 individuals (Fig. 5). The Critically Endangered Madagascar pochard (*Aythya innotata*) was represented by 163 individuals. Of the Endangered Bernier’s teal (*Anas bernieri*) 225 individuals were kept and of the likewise Endangered Meller’s duck (*Anas melleri*) 117 individuals (Fig. 5) (ZIMS, 2021).

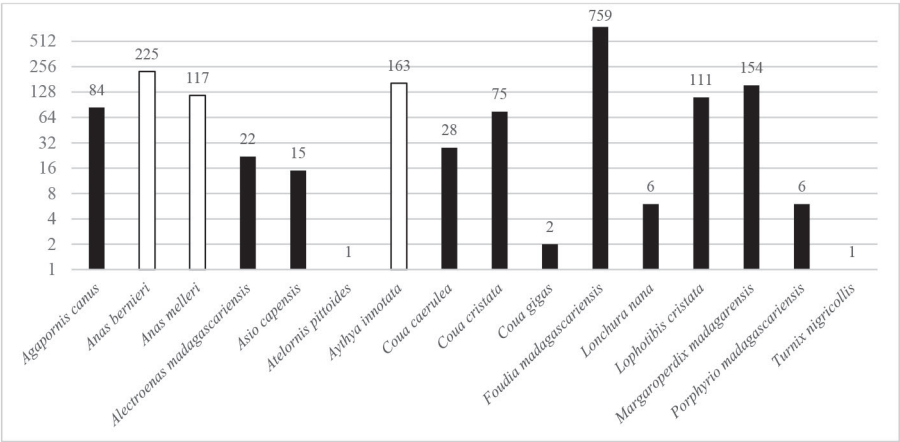


Fig. 5: Total number of endemic bird species of Madagascar (n = 1,769) kept worldwide according to ZIMS (2021), logarithmic scale; threatened species marked in white, non-threatened species marked in black (IUCN, 2021).

Among the threatened endemic bird species of Madagascar, the sex ratio was relatively balanced (Tab. 2), including one male that was surplus in the Critically Endangered *Aythya innotata*. In addition, there was a surplus of 13 males in the Endangered *Anas bernieri* and a surplus of 15 females in the Endangered *Anas melleri*.

Tab. 2: Total individuals and sex ratio of threatened and non-threatened endemic bird species in zoological institutions (m = male, f = female, u = unknown, ** = formerly kept), after IUCN (2021) and ZIMS (2021); threatened species are highlighted shaded.

| | IUCN category | Total individuals | Sex ratio (m, f, u) | Number of keeping institutions | Number of institutions with breeding success | Studbooks |
|-------------------------------------|---------------|-------------------|---------------------|--------------------------------|--|-----------|
| Family Anatidae | | | | | | |
| <i>Anas bernieri</i> | EN | 225 | 101,88,36 | 53 | 7 | EEP+SSP |
| <i>Anas melleri</i> | EN | 117 | 44,59,14 | 23 | 5 | EEP |
| <i>Aythya innotata</i> | CR | 163 | 79,78,6 | 1 | 1 | EEP |
| Family Brachypteraciidae | | | | | | |
| <i>Atelornis pittoides</i> | LC | 1 | 1,0,0 | | 1 | |
| Family Columbidae | | | | | | |
| <i>Alectroenas madagascariensis</i> | LC | 22 | 12,10,0 | | 4 | |

Tab. 2: Continued.

| | IUCN category | Total individuals | Sex ratio (m, f, u) | Number of keeping institutions | Number of institutions with breeding success | Studbooks |
|-----------------------------------|---------------|-------------------|---------------------|--------------------------------|--|-----------|
| Family Cuculidae | | | | | | |
| <i>Coua caerulea</i> | LC | 28 | 17,10,1 | 4 | | |
| <i>Coua cristata</i> | LC | 75 | 36,36,3 | 34 | 5 | SSP |
| <i>Coua gigas</i> | LC | 2 | 2,0,0 | 1 | | |
| Family Estrildidae | | | | | | |
| <i>Lonchura nana</i> | LC | 6 | 3,3,0 | 1 | | |
| Family Phasianidae | | | | | | |
| <i>Margaroperdix madagarensis</i> | LC | 154 | 49,40,65 | 24 | 5 | |
| Family Ploceidae | | | | | | |
| <i>Foudia madagascariensis</i> | LC | 759 | 98,110,551 | 39 | 8 | |
| Family Psittaculidae | | | | | | |
| <i>Agapornis canus</i> | LC | 84 | 39,28,17 | 9 | 1 | |
| Family Rallidae | | | | | | |
| <i>Porphyrio madagascariensis</i> | LC | 6 | 1,0,5 | 2 | | |
| Family Strigidae | | | | | | |
| <i>Asio capensis</i> | LC | 15 | 5,7,3 | 3 | | |
| Family Threskiornithidae | | | | | | |
| <i>Lophotibis cristata</i> | NT | 111 | 46,58,7 | 26 | 8 | SSP |
| Family Turnicidae | | | | | | |
| <i>Turnix nigricollis</i> | LC | 1 | 0,1,0 | 1 | | |

The non-threatened endemic bird species of Madagascar generally had a relatively balanced sex ratio. There was a male surplus (1-11) in *Agapornis canus*, *Alectroenas madagascariensis*, *Atelornis pittoides*, *Coua caerulea*, *C. gigas*, *Margaroperdix madagarensis*, *Porphyrio madagascariensis* and a female surplus (1-12) in *Asio capensis*, *Foudia madagascariensis*, *Lophotibis cristata* and *Turnix nigricollis*. (Tab. 2).

3.5. Institutions keeping Malagasy bird species

In total, there were 226 husbandries of endemic Malagasy bird species, whereby multiple counts were possible, as not every zoo exclusively kept one species. According to ZIMS, a total of 132 institutions worldwide kept at least one of the 16 held endemic Malagasy bird species. 77 of these 226 husbandries kept a threatened endemic Malagasy bird species (34%). 149 of the 226 institutions kept an endemic non-threatened Malagasy bird species (66%).

The Critically Endangered Madagascar pochard (*Aythya innotata*) was kept only in a single zoo. The Endangered Bernier's teal (*Anas bernieri*) was kept in 53 institutions and the Endangered Meller's duck (*Anas melleri*) in 23 institutions (Tab. 2). The largest ex situ populations among the non-threatened species were for *Foudia madagascariensis* (39), followed by *Coua cristata* (34), *Lophotibis cristata* (26), *Margaroperdix madagascariensis* (24), *Agapornis canus* (9), *Coua caerulea* (4), *Alectroenas madagascariensis* (4), *Asio capensis* (3), *Porphyrio madagascariensis* (2) and each one institution kept *Atelornis pittoides*, *Coua gigas*, *Lonchura nana* and *Turnix nigricollis* (Tab. 2)

3.6. Reproductive success of endemic Malagasy bird species

According to ZIMS, eight of the 16 endemic Malagasy bird species kept in zoos worldwide had successfully reproduced within the last 12 months. Three of the eight reproduced endemic Malagasy bird species were threatened (Tab. 2). The success rate of the non-threatened endemic bird species of Madagascar was 38% (5 out of 13 species) (Tab. 2).

The Critically Endangered Madagascar pochard (*Aythya innotata*) was bred in a single institution, while the Endangered Bernier’s teal (*Anas bernieri*) was bred in seven institutions and the Endangered Meller’s duck (*A. melleri*) in five institutions (Tab. 2).

The Critically Endangered Madagascar pochard (*Aythya innotata*) is managed by the Durrell Wildlife Conservation Trust in Jersey (UK) in a European Conservation Breeding Programme (EEP). The Endangered Bernier’s teal (*Anas bernieri*) and the Endangered Meller’s duck (*A. melleri*) are likewise managed in an EEP by the Durrell Wildlife Conservation Trust in Jersey (UK). The Endangered Bernier’s teal (*Anas bernieri*) is managed for the North American region by Louisville Zoo in a Species Survival Plan programme (ZIMS, 2021).

Of the five non-threatened endemic Malagasy bird species, one species was bred in a single zoo and four species in 5 to 8 zoos. *Lophotibis cristata* and *Foudia madagascariensis* were bred most often (Tab. 2).

In Europe, six endemic species reproduced successfully (*Anas bernieri*, *A. melleri*, *Margaroperdix madagarensis*, *Lophotibis cristata*, *Agapornis canus* and *Foudia madagascariensis*). In North America, three species reproduced successfully (*Anas bernieri*, *Coua cristata*, and *Lophotibis cristata*). One endemic threatened Malagasy bird species successfully reproduced in Africa (*Aythya innotata*) (Tabs 4-6).

There were a total of 44 offspring of *Anas bernieri*, 21 of *A. melleri* and four of *Aythya innotata*, all belonging to threatened species. Of the non-threatened species, there were offspring of one *Agapornis canus*, ten of *Coua cristata*, 140 of *Foudia madagascariensis*, 18 of *Lophotibis cristata* and eleven of *Margaroperdix madagarensis* (Tabs 4-6).

3.7. Unisexual collections of endemic Malagasy bird species

Whereas the Critically Endangered *Aythya innotata* was exclusively kept in mixed-sex groups, the proportion of single-sex individuals kept was 8% for the Endangered *Anas melleri* (9 out of 117 individuals, 7 out of 23 institutions keeping the species) and even 15% for the Endangered *Anas bernieri* (34 out of 225 individuals, 18 out of 53 institutions keeping the species) (ZIMS,

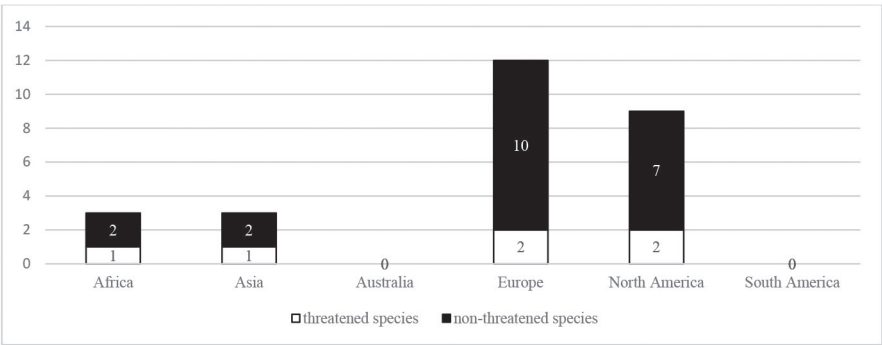


Fig. 6: Number of endemic Malagasy bird species kept per continent.

2021). Among the non-threatened endemic Malagasy bird species, one species was kept exclusively mixed-sex, *Lonchura nana*. In three species the proportion of single-sex individuals to the total number of individuals was 1-10%, in three species the proportion was 11-25%, in two species the proportion was 26-50% and in four species only individuals or single-sex groups were kept.

3.8. Threatened endemic Malagasy bird species that are not yet held in captivity

In total 25 threatened endemic (IUCN, 2021) bird species from Madagascar are not yet held in zoos worldwide according to ZIMS (Tab. 2).

3.9. Endemic Malagasy bird species held per continent

In Africa and Asia, one threatened and two non-threatened endemic Malagasy bird species were kept. Australian and South American zoos did not keep any endemic Malagasy bird species. European zoos held two threatened and ten non-threatened endemic Malagasy bird species. In North America, two threatened and seven non-threatened endemic Malagasy bird species were kept (Fig. 6) (Tab. 3).

Tab. 3: Number of institutions keeping endemic Malagasy bird species per continent; threatened species are highlighted in bold.

| Species | IUCN Status | Africa | Asia | Europe | North America |
|--|-------------|----------|----------|-----------|---------------|
| <i>Agapornis canus</i> (LC) | LC | | 1 | 7 | 1 |
| <i>Alectroenas madagascariensis</i> (LC) | LC | | | 4 | |
| <i>Anas bernieri</i> (EN) | EN | | | 39 | 14 |
| <i>Anas melleri</i> (EN) | EN | | 1 | 20 | 2 |
| <i>Asio capensis</i> (LC) | LC | 3 | | | |
| <i>Atelornis pittoides</i> (LC) | LC | | | 1 | |
| <i>Aythya innotata</i> (CR) | CR | 1 | | | |
| <i>Coua caerulea</i> (LC) | LC | | | 3 | 1 |
| <i>Coua cristata</i> (LC) | LC | | | 4 | 30 |
| <i>Coua gigas</i> (LC) | LC | | | 1 | |
| <i>Foudia madagascariensis</i> (LC) | LC | | | 37 | 2 |
| <i>Lonchura nana</i> | LC | | | 1 | |
| <i>Lophotibis cristata</i> (NT) | NT | | 3 | 16 | 7 |
| <i>Margaroperdix madagarensis</i> (LC) | LC | | | 21 | 3 |
| <i>Porphyrio madagascariensis</i> (LC) | LC | 2 | | | |
| <i>Turnix nigricollis</i> (LC) | LC | | | | 1 |

3.10. Richness analysis

According to ZIMS, a total of 131 institutions worldwide kept at least one of the 16 held endemic Malagasy bird species (Fig. 7), (Tabs 4-6).

In total, four Asian institutions kept an endemic Malagasy bird species. The Jurong Bird Park (Singapore) held a threatened endemic species, the Endangered Meller's duck (*Anas melleri*) (Tab. 4)

In Europe, there were 83 zoos with at least one endemic Malagasy bird species (ZIMS, 2021). The zoos in Zurich (9), Plzen (7), Cologne (7), Walsrode (6), Dvur Kralove (5) and Jersey (5) kept the most endemic Malagasy bird species.

In total, 49 of the 83 institutions in Europe kept a threatened endemic species. 12 zoos held both Endangered duck species from Madagascar (*Anas bernieri* and *A. melleri*) (Tab. 5).

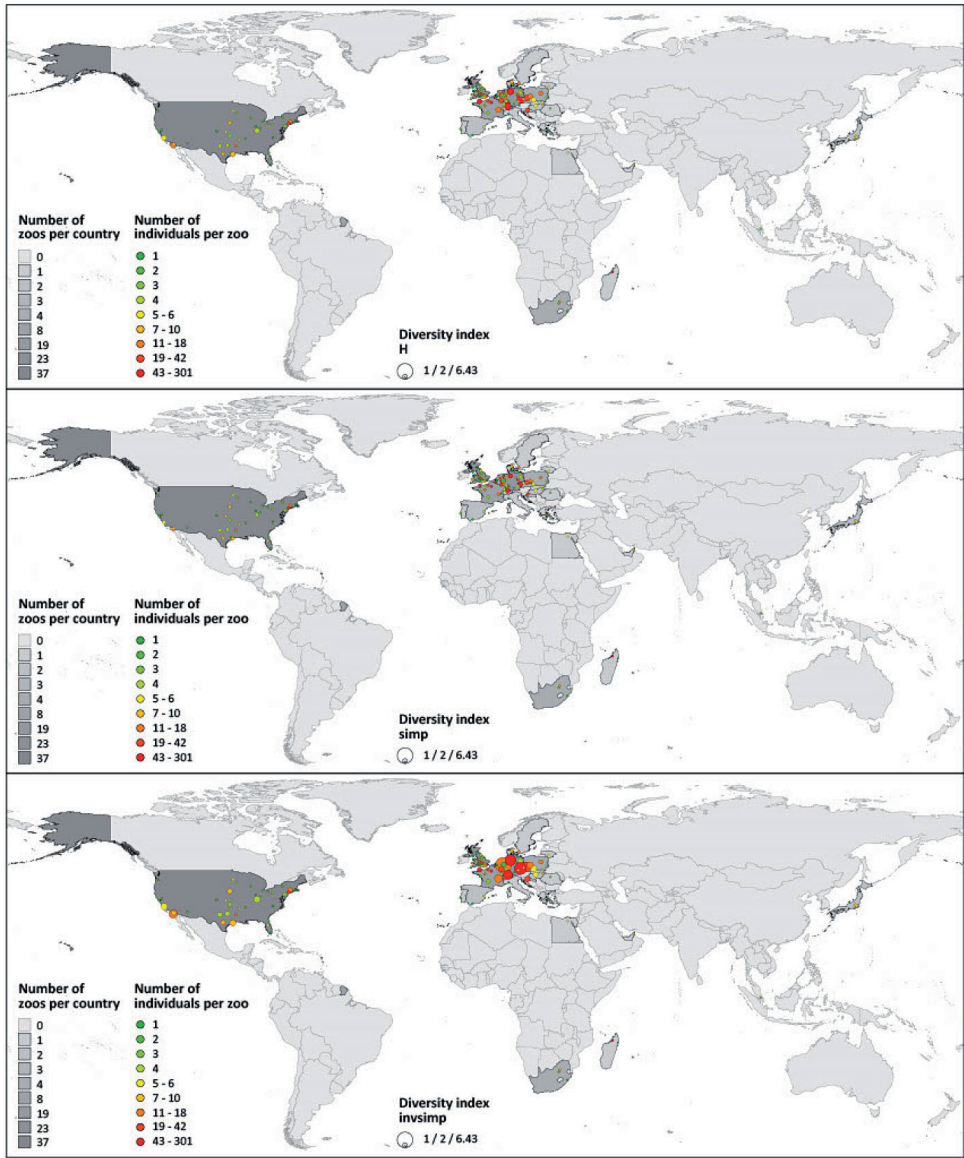


Fig. 7: Geographic distribution and diversity of endemic Malagasy bird species in zoos worldwide (n=131 institutions). H = Shannon-Weaver Index, J = Pielou's evenness, simp = Simpson Index (1-D) and invsimp = Inverse Simpson Index (1/D).

Endemic Malagasy bird species were kept in 38 North American zoos. The New York Bronx Zoo and San Diego Zoo had the most endemics (n = 4). Threatened endemic Malagasy bird species were kept in 14 of the 38 institutions in North America. Louisville Zoo and Litchfield Zoo each held two endemic threatened bird species. The remaining 12 zoos each held one threatened endemic bird species (Tab. 6).

Tab. 4: List of zoos in Africa and Asia that keep an endemic Malagasy bird species (offspring in brackets after species); threatened species are highlighted in bold.

| Zoo in Africa | Species | Zoos in Asia | Species |
|----------------|-----------------------------------|--------------------|---|
| Antsohihy | <i>Aythya innotata</i> (4) | Higashimatuyama | <i>Agapornis canus</i> , <i>Porphyrio madagascariensis</i> |
| Cairo | <i>Porphyrio madagascariensis</i> | Maliha | <i>Porphyrio madagascariensis</i> |
| Durban | <i>Porphyrio madagascariensis</i> | Singapore (Jurong) | <i>Anas melleri</i> |
| Johannesburg | <i>Asio capensis</i> | Tokyo (Ueno) | <i>Lophotibis cristata</i> |
| Vanderbijlpark | <i>Asio capensis</i> | | |
| Voma Velley | <i>Asio capensis</i> | | |

Tab. 5a: List of zoos in Europe (from A to PI) that keep an endemic Malagasy bird species (offspring in brackets after species); threatened species are highlighted in bold.

| Zoo | Species | Zoo | Species |
|----------------------|--|-------------------|--|
| Amersfoort | <i>Foudia madagascariensis</i> (1) | Heidelberg | <i>Anas bernieri</i> |
| Antwerp | <i>Margaroperdix madagarensis</i> | Helsingborg | <i>Agapornis canus</i> , <i>Foudia madagascariensis</i> |
| Arnhem | <i>Foudia madagascariensis</i> (1), <i>Lophotibis cristata</i> (1) | Jersey | <i>Anas bernieri</i> , <i>Anas melleri</i> (4), <i>Foudia madagascariensis</i> (10), <i>Lophotibis cristata</i> , <i>Margaroperdix madagarensis</i> |
| Arundel | <i>Anas melleri</i> | Karlsruhe | <i>Agapornis canus</i> , <i>Anas bernieri</i> , <i>Foudia madagascariensis</i> , <i>Margaroperdix madagarensis</i> |
| Augsburg | <i>Anas bernieri</i> | Kaunas | <i>Foudia madagascariensis</i> |
| Ballaugh | <i>Anas bernieri</i> | Kilgetty | <i>Foudia madagascariensis</i> |
| Berkshire | <i>Anas bernieri</i> | Kosice | <i>Anas bernieri</i> |
| Berlin (TP) | <i>Anas bernieri</i> , <i>A. melleri</i> | Krefeld | <i>Coa cristata</i> , <i>Lophotibis cristata</i> (4) |
| Berlin (Zoo) | <i>Anas bernieri</i> , <i>Lophotibis cristata</i> | Landau | <i>Foudia madagascariensis</i> , <i>Margaroperdix madagarensis</i> (1) |
| Bettembourg | <i>Anas bernieri</i> , <i>A. melleri</i> , <i>Foudia madagascariensis</i> | Lausanne | <i>Foudia madagascariensis</i> |
| Bourton-on-the-water | <i>Anas bernieri</i> | Leeds (Harewood) | <i>Margaroperdix madagarensis</i> |
| Bristol | <i>Anas melleri</i> | Leeds (Lotherton) | <i>Anas bernieri</i> |
| Budapest | <i>Anas bernieri</i> , <i>Foudia madagascariensis</i> | Leipzig | <i>Foudia madagascariensis</i> (43), <i>Lophotibis cristata</i> (2) |
| Burford | <i>Anas bernieri</i> , <i>Foudia madagascariensis</i> (1), <i>Margaroperdix madagarensis</i> | Lincoln (UK) | <i>Foudia madagascariensis</i> |
| Calviac | <i>Anas bernieri</i> , <i>A. melleri</i> | Lisbon | <i>Anas melleri</i> |
| Cambron | <i>Foudia madagascariensis</i> | Lisieux | <i>Anas bernieri</i> |
| Chester | <i>Foudia madagascariensis</i> (4) | London (Zoo) | <i>Anas bernieri</i> , <i>Lophotibis cristata</i> |
| Cologne | <i>Alectroenas madagascariensis</i> , <i>Anas bernieri</i> , <i>A. melleri</i> , <i>Coa caerulea</i> , <i>Coa cristata</i> , <i>Foudia madagascariensis</i> , <i>Lophotibis cristata</i> (1) | Magdeburg | <i>Anas bernieri</i> |
| Colwyn Bay | <i>Margaroperdix madagarensis</i> | Marlow | <i>Margaroperdix madagarensis</i> |
| Crawley | <i>Agapornis canus</i> , <i>Anas bernieri</i> , <i>Margaroperdix madagarensis</i> | Mechelen | <i>Anas bernieri</i> |
| Dortmund | <i>Anas bernieri</i> | Mulhouse | <i>Anas bernieri</i> (7), <i>Lophotibis cristata</i> |
| Dudley | <i>Anas melleri</i> | Newchurch | <i>Foudia madagascariensis</i> |
| Duisburg | <i>Anas melleri</i> | Newquay | <i>Margaroperdix madagarensis</i> |
| Dvur Kralove | <i>Agapornis canus</i> , <i>Anas bernieri</i> (6), <i>A. melleri</i> (4), <i>Foudia madagascariensis</i> , <i>Margaroperdix madagarensis</i> (3) | Opole | <i>Anas bernieri</i> (5) |

Tab. 5a: Continued.

| Zoo | Species | Zoo | Species |
|---------------|---|-------------|---|
| Emmen | <i>Foudia madagascariensis</i> , <i>Lophotibis cristata</i> | Osnabrück | <i>Foudia madagascariensis</i> |
| Fuengirola | <i>Anas melleri</i> | Ostrava | <i>Anas bernieri</i> , <i>Foudia madagascariensis</i> , <i>Margaroperdix madagarensis</i> |
| Gelsenkirchen | <i>Anas bernieri</i> | Oxton | <i>Anas melleri</i> |
| Genova | <i>Foudia madagascariensis</i> | Paris (Zoo) | <i>Anas bernieri</i> , <i>Foudia madagascariensis</i> , <i>Lophotibis cristata</i> |
| Graested | <i>Lonchura nana</i> | Plzen | <i>Agapornis canus</i> , <i>Alectroenas madagascariensis</i> , <i>Anas bernieri</i> (2), <i>A. melleri</i> , <i>Foudia madagascariensis</i> , <i>Lophotibis cristata</i> , <i>Margaroperdix madagarensis</i> |

Tab. 5b: List of zoos in Europe (from Pon to Z) that keep an endemic Malagasy bird species (off-spring in brackets after species); threatened species are highlighted in bold.

| Zoo | Species | Zoo | Species |
|-----------------|---|----------------------|---|
| Ponteland | <i>Anas bernieri</i> | Val de Reuil | <i>Foudia madagascariensis</i> , <i>Lophotibis cristata</i> |
| Port Saint Pere | <i>Anas bernieri</i> | Valencia (Bioparc) | <i>Anas melleri</i> (2) |
| Praha | <i>Lophotibis cristata</i> (2) | Villars les Dombes | <i>Anas bernieri</i> , <i>Foudia madagascariensis</i> , <i>Lophotibis cristata</i> , <i>Margaroperdix madagarensis</i> |
| Randers | <i>Foudia madagascariensis</i> , <i>Margaroperdix madagarensis</i> | Walsrode | <i>Alectroenas madagascariensis</i> , <i>Coua caerulea</i> , <i>C. cristata</i> , <i>C. gigas</i> , <i>Foudia madagascariensis</i> , <i>Lophotibis cristata</i> (2) |
| Reading | <i>Margaroperdix madagarensis</i> | Warsaw | <i>Anas bernieri</i> , <i>Foudia madagascariensis</i> (4), <i>Margaroperdix madagarensis</i> |
| Romsey | <i>Margaroperdix madagarensis</i> | Washington (UK) | <i>Anas melleri</i> |
| Sandown | <i>Anas melleri</i> | Watford | <i>Anas bernieri</i> |
| Sarthe | <i>Anas bernieri</i> , <i>A. melleri</i> (8) | Winchester (Marwell) | <i>Anas bernieri</i> |
| Sostofurdo | <i>Foudia madagascariensis</i> | Wroclaw | <i>Anas bernieri</i> , <i>A. melleri</i> , <i>Margaroperdix madagarensis</i> |
| Spatu | <i>Foudia madagascariensis</i> | Wuppertal | <i>Coua caerulea</i> , <i>Lophotibis cristata</i> |
| Straubing | <i>Foudia madagascariensis</i> | Zagreb | <i>Agapornis canus</i> , <i>Foudia madagascariensis</i> , <i>Margaroperdix madagarensis</i> (4) |
| Stuttgart | <i>Anas bernieri</i> (16) | Zamosc | <i>Foudia madagascariensis</i> |
| Tirgu-Mures | <i>Foudia madagascariensis</i> | Zurich | <i>Agapornis canus</i> (1), <i>Alectroenas madagascariensis</i> , <i>Anas bernieri</i> (7), <i>A. melleri</i> (3), <i>Atelornis pittoides</i> , <i>Coua cristata</i> , <i>Foudia madagascariensis</i> (76), <i>Lophotibis cristata</i> (5), <i>Margaroperdix madagarensis</i> (2) |

3.11. Protecded area coverage

The comparison of the distribution of protected areas with localities of all extant species shows that there are peaks in the species richness of total and threatened species on the east side of the central Malagasy mountain range. On the west side the distribution pattern is much more balanced with a relatively high species richness overall and a few smaller peaks at the coast. The corrected weighted endemism (CWE) analysis shows a similar distribution pattern (Fig. 8).

Tab. 6: List of zoos in North America that keep an endemic Malagasy bird species (offspring in brackets after species); threatened species are highlighted in bold.

| Zoo | Species | Zoo | Species |
|------------------|---|-------------------------|---|
| Abilene | <i>Anas bernieri</i> , <i>Coua cristata</i> | Minnesota | <i>Anas bernieri</i> |
| Akron | <i>Anas bernieri</i> | New York (Bronx) | <i>Agapornis canus</i> , <i>Coua cristata</i> , <i>Foudia madagascariensis</i> , <i>Lophotibis cristata</i> |
| Asheboro | <i>Coua cristata</i> | New York (Central Park) | <i>Coua cristata</i> |
| Atascadero | <i>Anas bernieri</i> , <i>Coua cristata</i> , <i>Margaroperdix madagarensis</i> | Omaha | <i>Coua cristata</i> (2), <i>Lophotibis cristata</i> |
| Attleboro | <i>Coua cristata</i> | Philadelphia | <i>Anas bernieri</i> , <i>Coua cristata</i> |
| Cincinnati | <i>Coua cristata</i> | Phoenix | <i>Lophotibis cristata</i> |
| Dallas | <i>Coua cristata</i> , <i>Lophotibis cristata</i> | Pittsburgh | <i>Coua cristata</i> |
| Freeport | <i>Margaroperdix madagarensis</i> | Portland | <i>Coua cristata</i> |
| Galveston | <i>Anas bernieri</i> , <i>Coua cristata</i> , <i>Lophotibis cristata</i> | Sacramento | <i>Coua cristata</i> |
| Garden City | <i>Coua cristata</i> | San Antonio | <i>Anas bernieri</i> , <i>Coua cristata</i> (1) |
| Houston | <i>Turnix nigricollis</i> | San Diego (Safari Park) | <i>Coua cristata</i> (3), <i>Lophotibis cristata</i> |
| Indianapolis | <i>Coua cristata</i> | San Diego Zoo | <i>Coua caerulea</i> , <i>Coua cristata</i> , <i>Lophotibis cristata</i> (1), <i>Margaroperdix madagarensis</i> |
| Lake Buena Vista | <i>Coua cristata</i> (3) | San Francisco | <i>Anas bernieri</i> |
| Litchfield | <i>Anas bernieri</i> , <i>A. melleri</i> | Shreveport | <i>Anas bernieri</i> (1), <i>Coua cristata</i> |
| Little Rock | <i>Anas bernieri</i> | St. Augustine | <i>Coua cristata</i> |
| Louisville | <i>Anas bernieri</i> , <i>A. melleri</i> , <i>Foudia madagascariensis</i> | Syracuse | <i>Coua cristata</i> |
| Memphis | <i>Coua cristata</i> | Toledo | <i>Coua cristata</i> |
| Miami | <i>Coua cristata</i> | Tulsa | <i>Anas bernieri</i> , <i>Coua cristata</i> |
| Milwaukee | <i>Anas bernieri</i> | Wichita | <i>Coua cristata</i> (1) |

3.11. Protected area coverage

The comparison of the distribution of protected areas with localities of all extant species shows that there are peaks in the species richness of total and threatened species on the east side of the central Malagasy mountain range. On the west side the distribution pattern is much more balanced with a relatively high species richness overall and a few smaller peaks at the coast. The corrected weighted endemism (CWE) analysis shows a similar distribution pattern (Fig. 8).

Further analysis revealed that of the 28 threatened endemic species there are 7 with habitats that are mostly outside of the currently extant PAs. These are *Actophilornis albinucha*, *Anas bernieri*, *Ardea humbloti*, *Calicalicus rufocarpalis*, *Charadrius thoracicus*, *Haliaeetus vociferoides* and *Zapornia olivieri*.

Considering the suitability of the habitats of these species the bird *C. thoracicus* stands out due to only marginal suitability of almost half of its inhabited areas (Fig. 8). This applies to its habitats at the marine coast and intertidal regions on sandy shoreline and/or beaches, sand bars and dunes, spits, mud and salt flats.

Of the two Critically Endangered endemic species *Aythya innotata* and *Haliaeetus vociferoides* (IUCN, 2021), the habitat of *A. innotata* is protected in the Lac Alaotra National Park (Fig. 9). *H. vociferoides* is mostly spread along the western coast without sufficient PA protection (Fig. 9).

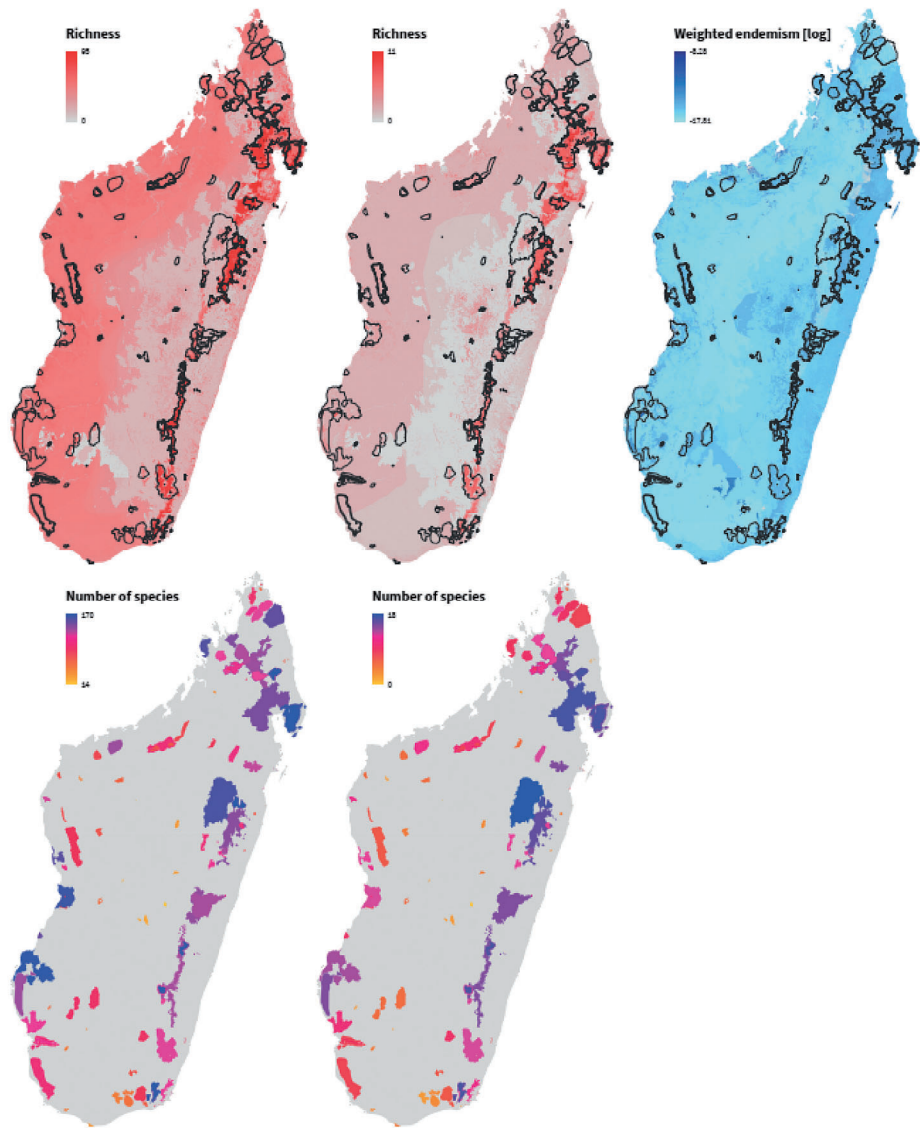


Fig. 8: Richness analysis of all extant species (upper row left) and threatened species (upper row middle). Corrected weighted endemism (CWE) (upper row right); number of species in protected areas (lower row left) and number of threatened species in protected areas (lower row middle).

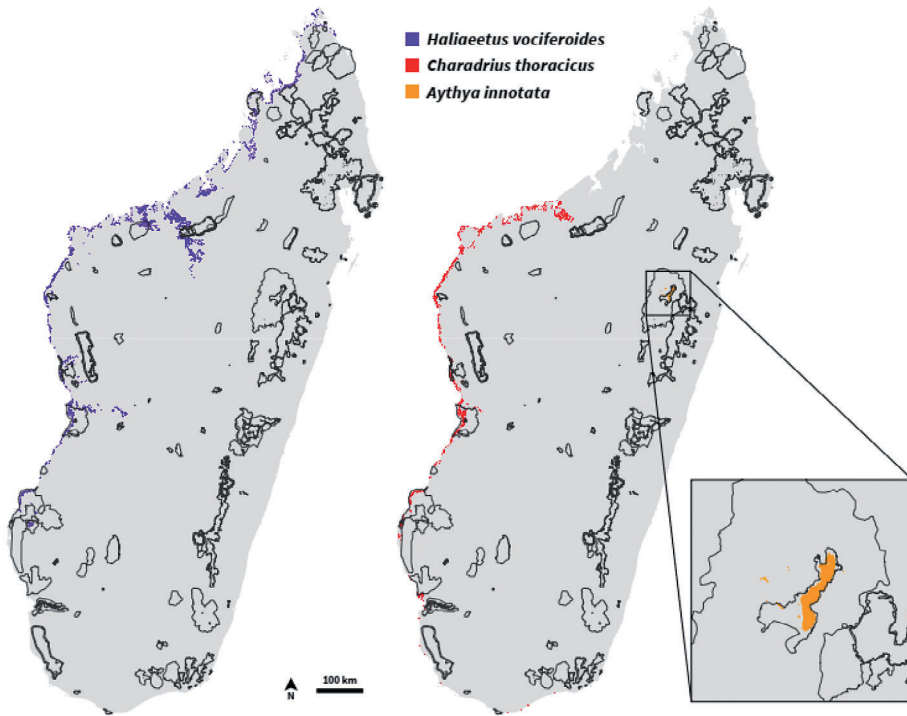


Fig. 9: Habitats of the species *Charadrius thoracicus* and the Critically Endangered species *Aythya innotata* and *Haliaeetus vociferoides*.

4. Discussion

Of the 195 Malagasy bird species, 142 occur exclusively in the Malagasy region, comprising Madagascar and surrounding islands, such as Reunion, Comoros or Mayotte. Of these 142 bird species, 117 are endemic to Madagascar. Currently 24% of the endemic Malagasy bird species are threatened, of which two are Critically Endangered, 11 Endangered and 15 Vulnerable (IUCN, 2021). Declining populations have been reported for 70 of the 117 endemic bird species and for 25 of the 28 threatened endemic Malagasy bird species (IUCN, 2021). As the most recent evaluation for 89 of 117 endemic Malagasy bird species was at least five years ago, re-assessments might lead to even more alarming results. The threat of Madagascar's endemic bird families and their species is considered high, as 27% (3 out of 11 species) of the Endangered and 66.6% (10 out of 15 species) of the Vulnerable endemic Malagasy bird species derive from one of the endemic families (IUCN, 2021).

According to the ZIMS analysis 16 endemic Madagascar bird species are kept and three of them are threatened. The number of three endemic threatened Malagasy bird species in zoos represents only 11% of the 28 currently recognised endemic threatened Malagasy bird species according to ZIMS data. However, not all zoos worldwide are connected to ZIMS (Species360, 2021). This study does not take into account Malagasy bird species kept privately. Nevertheless, it can be assumed that 89% of the 28 threatened endemic bird species (i.e. 25 species) are not kept ex situ.

Ex situ populations of Madagascar's threatened bird species should be expanded to create insurance colonies. This applies in particular to the Critically Endangered Madagascar pochard (*Aythya innotata*), an island endemic, and the two Endangered bird species from the Madagascar region, the Madagascar ibis (*Threskiornis bernieri*) and Madagascar pond-heron (*Ardeola idae*), currently held in only a few institutions (*Aythya innotata*: 1, *Ardeola idae*, *Threskiornis bernieri*: 7 institutions).

A first step in this direction were transfers of *Threskiornis bernieri* and *Ardeola idae*, which occur in the Malagasy region, from Weltvogelpark Walsrode (Germany) to the USA in 2020 to establish the first zoo population of these species in the USA.

In addition to aforementioned transfers, individuals of these two species also were sent to other European institutions. Previously, Weltvogelpark Walsrode was the only institution keeping these bird species.

The focus of keeping endemic Malagasy bird species is particularly in Europe and North America (Fig. 7). However, there also are distinctively more zoos from Europe and North America that participate in ZIMS, compared to institutions from the tropics such as Africa. Numerous zoos with endemic Malagasy bird species are represented in particular in Central Europe. In southern Europe, the density of Malagasy bird endemics held is much lower, although the climatic conditions would be optimal. The endemic Malagasy bird species are represented in 132 zoos worldwide (Fig. 7). Threatened endemic Malagasy bird species are kept in even smaller numbers (65 of 132 zoos worldwide with endemic Malagasy bird species) (Tabs 4-6). Overall, it is striking that mostly non-threatened bird species are kept. The future focus in husbandry should be on threatened bird species, especially endemic taxa with a small-scale distribution. This is also reflected by the fact that only 8% of birds kept worldwide are threatened, compared to 23% of kept mammals (Conde et al., 2013).

To ensure the management and care of threatened bird species in zoos, it is advisable to question the current species collections in zoos. There are opportunities to replace non-threatened bird species with threatened taxa without fundamentally changing the husbandry conditions. For example, *Ardeola idae* could be considered a replacement for some smaller heron species, such as *Bubulcus ibis*. *B. ibis* was assessed in the analysis with 1268 individuals (ZIMS, 2021) and an IUCN status of LC. *Threskiornis bernieri* could replace *T. aethiopicus*. In total, 1480 individuals of *T. aethiopicus* were held as of 12/04/2021 (ZIMS, 2021) and this species is non-threatened (IUCN, 2021). These measures could further increase the current population numbers in zoos and provide an ex situ insurance population. Recommendations for all threatened species can be found in Tab. 7.

The three threatened endemic Malagasy bird species kept could all be reared in the last 12 months according to ZIMS. Breeding success was higher in the threatened species than in the non-threatened species. For the threatened endemic Malagasy bird species, the success rate of the species kept was 100% while only 42% (5 out of 13 species) of the non-threatened endemic Malagasy bird species were reared. There was a balanced sex ratio in the threatened endemic bird species, so future breeding success of these three species should not be a problem.

In the past, two further species of the 28 threatened endemic bird species of Madagascar were kept (*Monias benschi* and *Uratelornis chimaera*), but they have since disappeared from collections (Tab. 7).

Space in zoos is limited and zoos often hold on to their existing populations of species, with changes often occurring hesitantly. Bringing ambitious private keepers into a conservation breeding network and by doing so expanding that network could be crucial. A conservation breeding network means that private individuals who have an expertise are allowed to breed protected and threatened species. The offspring is returned to the breeding network and placed with other institutions or private individuals. Examples are Citizen Conservation or similar initiatives (e.g. the Fruit Dove Project). The German based initiative Citizen Conservation aims to connect full-time animal keepers and private keepers under regulated and controlled conditions (Citizen Conservation, 2021). Currently,

Citizen Conservation focuses on amphibians and fishes, but an expansion to other animal groups is planned. The aim of the Fruit Pigeon Project in Europe (Weber, 2008) is to exchange husbandry and breeding experiences and to coordinate the population both in zoos and among private breeders. The more institutions and holders are integrated in such a conservation breeding network, the easier it will be to exchange animals and the genetic variability remains high.

In Madagascar, there are also ex situ conservation activities implemented, such as a breeding centre in Antsohihy where ducklings of *Aythya innotata* are raised for later release into the wild. Ampasy Research Station enables in situ study of local species and habitat, offer environmental education to the local communities and conserve and restore the surrounding forests and species within (Birdlife, 2020).

Natural populations are threatened amongst others due to ongoing deforestation (Harper, 2007). On-site species conservation is most important, with ex situ measures currently being the most effective alternative to protect threatened bird species (Conde et al., 2013). The comparison of the distribution of protected areas with localities of endemic and threatened endemic species revealed that PAs in the northeast and east of the country provide a relatively good protection for several endemic and threatened endemic species. There is still a need for expansion though since the PAs in the west and southwest do not cover many of threatened endemic species. There are 7 threatened endemic species that are poorly protected by the existing PAs: *Actophilornis albinucha*, *Anas bernieri*, *Ardea humbloti*, *Calicalicus rufocarpalis*, *Charadrius thoracicus*, *Haliaeetus vociferoides* and *Zapornia olivieri*. Since their habitats all lay in the west and southwest coastal regions it is recommended to expand the current protected area system into these regions. Especially regarding the species *C. thoracicus*, which is listed VU in the IUCN Red List with a decreasing population number (IUCN, 2021), it is advisable to protect its suitable marine coastal and supratidal habitat in the coastal brackish, saline lagoons and marine lakes as well as tropical mangrove vegetation above high tide level and grasslands. The same applies to *H. vociferoides*, which is listed as CR (IUCN, 2021) and therefore of high priority for conservation efforts.

Finally, the combination of in situ and ex situ protection measures will synergistically help to preserve species diversity (CPSG, 2021). Of the endemic Malagasy bird species two are Critically Endangered and eleven Endangered, but of these one Critically Endangered (50 %) and nine (82 %) Endangered endemic Malagasy bird species are not yet kept (Tab. 7). As a matter of urgency, some species should be transferred into ex situ conservation projects after a needs assessment to prevent the loss of a particular species due to unforeseen local events such as disease outbreaks, acute habitat loss and natural disasters.

For the species that also occur on the African mainland, no increased breeding efforts need to be made at present. All species are non-threatened according to IUCN (2021), only the Lesser Flamingo (*Phoeniconaias minor*) is Near Threatened and thus is an exception. On the contrary, as another example, the Critically Endangered Madagascar Sea Eagle (*Haliaeetus vociferoides*) is in severe need of improved habitat protection measures, as *H. vociferoides* is without sufficient PA protection. For the build-up of a conservation breeding programme, the threatened species could easily replace other eagle species that are non-threatened at all. As Madagascar Sea Eagles lay two eggs of which only one young is finally raised, the second egg or fledgling could be taken from the nest in the field to be reared and build up an ex situ population for later release as was already performed in the past (Watson, 1996).

As new bird species continue to be discovered (e.g. *Mentocrex beankaensis* [2011] [IUCN, 2021]), ornithological field research should be continued as well. Such field research could also be linked with conservation breeding efforts, when ex situ action is necessary (IUCN/SSC, 2014).

However, ex situ measures should always be complementary to, and not a substitute for, in situ efforts and actions (Conde et al., 2011). Only if groups of experts work together, species conservation can be guaranteed in the best way (CPSG, 2021). With this research we intended

Tab. 7a: Recommendations for all threatened bird species of Madagascar. Replacement recommendation according to Leiss et al. (2021). Families Accipitridae, Anatidae, Ardeidae, Bernieridae, Brachypteraciidae, Charadriidae, Glareolidae, Jacanidae, Mesithornithidae and Muscipidae. Superscript RE = regionally endemic; x= urgent, xx= more urgent, xxx = most urgent.

| Family | Establish situ | ex population | Increase number of holders | Keep stock at this level | Husbandry experience | replacement recommendation |
|---|-------------------|------------------|-------------------------------|-----------------------------|---------------------------------|----------------------------------|
| <i>Species and IUCN Status</i> | | | | | | |
| Accipitridae | | | | | | |
| <i>Accipiter henstii</i> (VU) | x | | | | | |
| <i>Circus macrosceltes</i> (EN) ^{RE} | xx | | | | | <i>Milvus migrans</i> (LC) |
| <i>Eutriorchis astur</i> (EN) | xx | | | | | <i>Milvus migrans</i> (LC) |
| <i>Haliaeetus vociferoides</i> (CR) | xxx | | | | | |
| Anatidae | | | | | | |
| <i>Anas bernieri</i> (EN) | | | | x | Zoo expertise | |
| <i>Anas melleri</i> (EN) | | | | x | Zoo expertise | |
| <i>Aythya immotata</i> (CR) | | | xxx | | Zoo expertise | |
| Ardeidae | | | | | | |
| <i>Ardea humbloti</i> (EN) ^{RE} | xx | | | | | <i>Ardea purpurea</i> (LC) |
| <i>Ardeola idae</i> (EN) ^{RE} | | | xx | | | <i>Bubulcus ibis</i> (LC) |
| Bernieridae | | | | | | |
| <i>Xanthomixis apperti</i> (VU) | xx | | | | | |
| Brachypteraciidae | | | | | | |
| <i>Brachypteracias leptosomus</i> (VU) | xxx | | | | Zoo expertise for | |
| <i>Geobiates squamigera</i> (VU) | xxx | | | | <i>Uratelornis chimaera</i> | |
| <i>Uratelornis chimaera</i> (VU) | xxx | | | | (VU) | |
| Charadriidae | | | | | | |
| <i>Charadrius thoracicus</i> (VU) | x | | | | | <i>Charadrius hiaticula</i> (LC) |
| Glareolidae | | | | | | |
| <i>Glareola ocularis</i> (VU) | x | | | | | |
| Jacanidae | | | | | | |
| <i>Actophilornis albinucha</i> (EN) | xx | | | | | |
| Mesithornithidae | | | | | | |
| <i>Mesitornis unicolor</i> (VU) | xxx | | | | Zoo expertise for | |
| <i>Mesitornis variegatus</i> (VU) | xxx | | | | <i>Atelornis pittoides</i> (LC) | |
| <i>Monias benschi</i> (VU) | xxx | | | | und <i>Monias benschi</i> (VU) | |
| Muscipidae | | | | | | |
| <i>Monticola erythronotus</i> (EN) | xx | | | | | |

Tab. 7b: Recommendations for all threatened bird species of Madagascar. Replacement recommendation according to Leiss et al. (2021). Families Philepittidae, Podicipedidae, Rallidae, Sarratoruridae, Scolopacidae, Threskiornithidae, Tytonidae and Vangidae. Superscript RE = regionally endemic; xxx = most urgent.

| | | | | | | |
|-------------------------------------|-----|--|--|--|---------------------------|------------------------------------|
| Philepittidae | | | | | | |
| <i>Neodrepanis hypoxantha</i> (VU) | xxx | | | | | |
| Podicipedidae | | | | | | |
| <i>Tachybaptus pelzennii</i> (EN) | x | | | | Zoo and private expertise | <i>Tachybaptus ruficollis</i> (LC) |
| Rallidae | | | | | | |
| <i>Rallus madagascariensis</i> (VU) | x | | | | | <i>Gallinula chloropus</i> (LC) |

Tab. 7b: Continued.

| Family | Establish ex situ population | Increase number of holders | Keep stock at this level | Husbandry experience | replacement recommendation |
|---|---------------------------------|-------------------------------|-----------------------------|-------------------------------|--------------------------------------|
| <i>Species and IUCN Status</i> | | | | | |
| <i>Zapornia olivieri</i> (EN) | xx | | | | <i>Gallinula chloropus</i> (LC) |
| Sarothruridae | | | | | |
| <i>Sarothrura watersi</i> (EN) | xx | | | | <i>Gallinula chloropus</i> (LC) |
| Scolopacidae | | | | | |
| <i>Gallinago macrodactyla</i> (VU) | x | | | | |
| Threskiornithidae | | | | | |
| <i>Threskiornis bernieri</i> (EN) ^{RE} | | xx | | | <i>Threskiornis aethiopicus</i> (LC) |
| Tytonidae | | | | | |
| <i>Tyto soumagnei</i> (VU) | x | | | | <i>Tyto alba</i> (LC) |
| Vangidae | | | | | |
| <i>Calicalicus rufocarpalis</i> (VU) | xx | | | Zoo Expertise for | |
| <i>Euryceros prevostii</i> (EN) | xxx | | | <i>Falculea palliata</i> (LC) | |
| <i>Newtonia fanovanae</i> (VU) | xxx | | | | |
| <i>Oriolia bernieri</i> (EN) | xxx | | | | |
| <i>Xenopirostris damii</i> (EN) | xxx | | | | |

to provide a basis for improved ex situ conservation breeding measures and expansion of the conservation breeding network for threatened endemic Malagasy birds. This study can be used as a guideline to improve zoo collections and thus ex situ measures in general.

5. Outlook and recommendations

In general, intensive breeding efforts should be made for species that have not yet been successfully bred. Here, focus should be laid on threatened species and those ones that have not been assessed so far but may be evaluated as threatened. A sensible way forward for species conservation is to initially create breeding or conservation centres in Madagascar (Barongi, 2015), similar to the Endangered Primate Rescue Centre in Vietnam (EPRC, 2020) or to Prigen Conservation Breeding Ark in Indonesia (Menner, 2020). Ideally, such conservation breeding programmes could be extended to zoos in other countries to stabilise the conservation breeding programmes and develop an international network. Consideration should be given to including threatened species that are not yet in zoos in strategic and managed conservation breeding programmes. The legal basis for this needs to be established with local authorities. Zoos in Europe and North America should gradually replace non-threatened species with threatened species, for example *Bubulcus ibis* with *Ardeola idea*. Space should be planned for the addition of further threatened Malagasy species. Further studbooks, as already performed for the three threatened endemic Malagasy bird species in zoo husbandries, need to be established. We recommend to first focus on the threatened species from the endemic bird families and subsequently on the remaining threatened endemic species, giving those ones priority that have a restricted range only, such as the Endangered *Xenopirostris damii* (Tab. 3).

Ex situ activities on local level are always best, but in poor countries there is a lack of money, facilities and knowledge, and therefore a lack of long-term security. Therefore, these countries should receive improved support from western/northern nations. The build up of outside range activities are in particular important as additional support to safeguard species in cases of catastrophic events, disease outbreaks or political unrest (e.g., Jacken et al., 2020). These suggested ex situ measures need to be integrated with suitable in situ measures (tree planting, alternative livelihoods, involvement of local communities in conservation measures, education). Here, zoos

need to create the basis for success through projects with local partners and a voice in politics. Combining several zoos into one project can be advantageous here, as it provides a larger financial basis for the project and thus also a larger reach and perception for local politics. The following zoos are good examples for having been built up cooperation projects in Madagascar: Durrell Wildlife Conservation Trust Center, which protects the forests, teaches sustainable farming, works with law enforcement, protects freshwater turtles and saves the world's rarest duck. DWCC's Project Angonoka has saved the Angonoka tortoise (*Astrochelys yniphora*) from extinction and initiated a local education programme in the Menabe Region. A breeding station for the Bernier's teal has been established in Jersey. AEECL is an association of European zoos and institutes, through whose initiative and funding the Sahamalaza-Iles Radama National Park in Madagascar was established and continues to be maintained. Zurich Zoo contributes US\$ 125,000 annually to the operating costs and sustainability funds of Masoala National Park. In addition, projects for rainforest conservation, reforestation, sustainable agriculture, water supply and hygiene as well as school education for children are supported in surrounding communities.

Zusammenfassung

Wir haben untersucht, für welche bedrohten endemischen madagassischen Vogelarten bereits Zoopopulationen existieren und für welche bedrohten Arten noch keine ex-situ-Erhaltungsmaßnahmen ergriffen wurden. Um einen Überblick über die in Zoos gehaltenen madagassischen Vogelarten zu erhalten, wurden die Anzahl der gehaltenen Individuen, die Anzahl der haltenden Institutionen und die erfolgreiche Reproduktion innerhalb der letzten zwölf Monate analysiert, basierend auf der Datenlage aus der ZIMS-Datenbank (Species360, Bloomington, MN, USA), ergänzt durch Daten aus der Datenbank Zootierliste (ZTL: <https://zootierliste.de/>). Von den 195 madagassischen Vogelarten kommen 142 ausschließlich in der madagassischen Region vor, die Madagaskar und die umliegenden Inseln umfasst. Von diesen 142 Vogelarten sind 117 auf Madagaskar endemisch. Gegenwärtig sind 28 (24 %) der endemischen madagassischen Vogelarten laut IUCN als bedroht eingestuft, von denen zwei vom Aussterben bedroht, 11 stark gefährdet und 15 gefährdet sind. Insgesamt 62 madagassische Vogelarten werden weltweit in Zoos gehalten, von denen nur 23 in der madagassischen Region allein vorkommen und 15 endemisch auf Madagaskar sind. Insgesamt 131 Einrichtungen weltweit hielten mindestens eine der 15 endemischen madagassischen Vogelarten. Drei der fünfzehn gehaltenen endemischen madagassischen Vogelarten sind bedroht, von denen eine in der IUCN die Kategorie „vom Aussterben bedroht“ ist und zwei „stark gefährdet“ sind. Somit sind nach unserer Studie mindestens 25 (89 %) der 28 bedrohten endemischen madagassischen Vogelarten nicht durch ex-situ-Bestände abgedeckt. Insgesamt acht der fünfzehn endemischen madagassischen Vogelarten, die weltweit in Zoos gehalten werden, haben sich laut ZIMS innerhalb der letzten zwölf Monate erfolgreich fortgepflanzt. Drei der acht reproduzierten endemischen madagassischen Vogelarten waren bedroht. Eine Richness-Analyse, die untersucht hat, wie die Zoos, die madagassische Vögel halten, im globalen Maßstab verteilt sind, ergab, dass die derzeitigen Zoobestände bedrohter endemischer madagassischer Vogelarten hauptsächlich in Europa und Nordamerika konzentriert sind. Eine Analyse der Schutzgebietsabdeckung, das heißt ein Vergleich der Verteilung der Schutzgebiete mit den Fundorten endemischer und bedrohter endemischer Arten, zeigte, dass das bestehende Schutzgebietssystem für mehrere bedrohte endemische Arten nicht ausreichend ist. Wir geben Empfehlungen für die Umstellung der Haltung von nicht bedrohten Arten, wie *Bubulcus ibis*, auf bedrohte Arten wie *Ardeola idae*. Arten aus endemischen Familien sollten im Fokus von neuen ex-situ-Haltungen stehen und die

Haltung der vom Aussterben bedrohten Arten sollte begonnen (*Haliaeetus vociferoides*) oder ausgebaut werden (*Aythya innotata*). Für diese Arten liegen Erfahrungswerte, ob nun positiv oder negativ, aus der Vergangenheit vor oder Erfahrungen mit der Haltung von nahe verwandten Arten. Mit dieser Studie legen wir eine Grundlage für verbesserte Ex-situ-Erhaltungszuchtmaßnahmen und den Ausbau des Erhaltungszuchtnetzes für bedrohte endemische madagassische Vogelarten vor, was dem von der IUCN SSC Conservation Planning Specialist Group (CPSG) vorgeschlagenen One Plan Approach entspricht.

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