JZAR JOURNAL OF ZOO AND AQUARIUM RESEARCH
www.jzar.org

Research article

Passerine birds in zoos: A global approach on distribution patterns and conservation breeding of threatened birds in zoological institutions

Anna Wahle[1], Laura Leiss[1], Bernd Marcordes[1], Theodor B. Pagel[1,2] and Thomas Ziegler[1,2]

[1]AG Zoologischer Garten Köln, Riehler Str. 173, 50735 Köln, Germany
[2]Institute of Zoology, University of Cologne, Zülpicher Straße 47b, 50674, Germany

Correspondence, Thomas Ziegler, email; ziegler@koelnerzoo.de

Keywords: Birds, conservation breeding, ex situ populations, Passeriformes, species selection, ZIMS, Zoos

Article history:
Received: 16 Jan 2023
Accepted: 16 Jan 2024
Published online: 31 Jan 2024

Abstract

For population management of threatened species according to the IUCN Conservation Planning Specialist Group's One Plan Approach, knowledge about in-situ and ex-situ populations is required. To enhance the conservation of threatened birds and improve zoos' participation in the One Plan Approach the following passerine bird data from the Zoological Information Management System (ZIMS) was analysed: individual numbers, breeding success and number of holding institutions. Species were categorised as threatened, non-threatened or not evaluated based on IUCN Red List assessments. Only 830 (~12.5%) of 6,659 recognised passerine bird species are held in ZIMS institutions worldwide, mostly in Europe, North America and Asia. Approximately 95% of the species kept globally are classified as non-threatened and ~4% (34 species) are threatened. Only 24% of the species kept successfully bred in 2021, 40% in only one zoo each. Of the threatened species, 18 reproduced. Approximately 31% of threatened species are kept in only one zoo. More than half of the species kept are represented by less than 10 individuals. Thus, conservation of threatened passerine birds in zoos needs improvement. A shift towards keeping threatened species should be considered within management programmes in human care. The expansion of conservation breeding networks should be used to secure ex-situ populations. Cooperative projects with institutions and stations in species-rich hotspots could greatly benefit passerine bird conservation by supporting future reintroductions. Thus, according to the One Plan Approach, ex-situ populations could directly contribute to in-situ protection.

Introduction

Nature is declining worldwide at a rate not seen in millions of years. The decline of individual populations and global species extinctions characterise the current sixth mass extinction (Ceballos et al. 2017; World Wide Fund For Nature (WWF) 2020). Presently, there are more than 147,500 species on the International Union for Conservation of Nature (IUCN) Red List. A total of 28% of all species are listed as threatened with extinction (IUCN 2022). The major drivers for biodiversity loss are caused mainly by human activities, such as habitat loss due to land or sea use changes, overexploitation of animals, plants or other organisms and pollution (IPBES 2019, Newbold et al. 2015). Genetic variability, species richness, populations and ecosystems are adversely affected. Biodiversity is essential to human life on Earth and is being destroyed at an unprecedented rate. Species population trajectories are important indicators of ecosystem health (WWF 2020).

The class of birds includes 11,162 described species (BirdLife International 2022a). Even for generally well-known taxa like birds, species remain to be discovered. For example the Principe Scops-Owl *Otus bikegila* was only discovered in 2016 and officially described in 2022 (Melo et al. 2022). Birds are among the most important species for ecosystems. They play

an important role in preserving natural systems, including cleaning up waste, spreading seeds and controlling pests (Donoso et al. 2020; Whelan et al. 2015). The provision and quality of many ecosystem services are positively correlated to bird abundance and species richness (García and Martínez 2012; Gaston et al. 2018).

The described bird species belong to 40 orders. The Passeriformes, on which this study focuses, is one of these 40 orders, and contains 60% of all bird species. It comprises three suborders with large differences in diversity and distribution (Tietze 2018). One of these, the oscines (Passeri), comprises 45% of all described bird species. These bird species inhabit all continents. The suboscines (Tyranni) contain 15% of all bird species and their distribution is restricted to South America. The third suborder of the New Zealand wrens (Acanthisitti) includes only two extant species.

Rosenberg et al. (2019) identified that in North America only 29% of the bird population from 1970 still exists, equating to a loss of three billion birds in just 53 years. In total ~10% of all described passerine bird species are globally threatened, primarily from logging, agriculture, trapping and climate change (IUCN 2022). Approximately 14% of globally threatened species are Critically Endangered because of small and declining populations, posing a high risk of extinction in the future (BirdLife International 2022b). Protected areas are essential to save biodiversity from habitat loss. But there is an urgent need for improvement; the network of protected areas is incomplete and inefficiently managed (Hoffmann et al. 2010).

The One Plan Approach by the IUCN Conservation Planning Specialist Group (CPSG) proposes a combination of population management and conservation measures, both in situ and ex situ (Byers et al. 2013). In the process, zoos are becoming more effective conservation organisations by more strongly integrating ex situ populations into species conservation efforts (Byers et al. 2013). The potential for zoos to make an important contribution to species conservation could be enabled in several ways. According to the Nature Conservancy and the global network of the World Wildlife Fund, World Association of Zoos and Aquariums (WAZA) members represent the third largest financial donor to conservation worldwide (Gusset and Dick 2011).

The European Association of Zoos and Aquaria (EAZA) runs campaigns like the Silent Forest campaign (2017–2019) to raise awareness and funds for important conservation issues (EAZA 2022a). The Silent Forest campaign aimed to save threatened songbirds in Asia by strengthening knowledge and awareness inside and outside the zoo community of trade in these threatened species. In Asia, songbirds face extinction due to illegal trade, competition against other species and hunting for medicine and food (EAZA 2022a).

By providing husbandry expertise, capacity and resources, modern zoos are essential to both research on and conservation management of threatened species, such as conservation breeding and reintroduction (Barongi et al. 2015; Conde et al. 2011). In cases of immediate threats like disease outbreaks, invasive species, natural catastrophes, political unrest or other destructive events, ex situ conservation is often essential for species survival (Jacken et al. 2020).

Zoos provide great research opportunities for poorly known species, enhancing knowledge on husbandry and reproduction for future reintroductions (Conde 2013; Conde et al. 2011; Fa et al. 2014; Miller et al 2004). For conservation research and action, databases are an essential tool, as they can highlight conservation priorities (e.g. Jacken et al. 2020; Rech et al. 2023). Since space and financial resources are limited in most zoos, it is of utmost importance to use capacities optimally for the protection of threatened species. The Zoological Information Management System (ZIMS) is a class-leading database for recording information and facilitating data exchange (Barongi et al. 2015; ZIMS 2021) and can help to improve collection planning in zoos.

This study aimed to provide an overview of current passerine zoo populations and their global threat status. Based on these data, conclusions can be drawn for improvements regarding the conservation contribution of zoos. For this purpose, ZIMS and Zootierliste data were collected, compared and analysed. IUCN Red List threat assessments were also considered.

Material and methods

Species holding data

A table of all currently described passerine bird genera (with respective species numbers), families and orders based on the taxonomy in Bird Families of the World (Winkler et al. 2015) was compiled in October 2021.

The listed genera were analysed in the Species360 database ZIMS. Between October and November 2021, available population reports for each species, including the number of individuals held, the number of institutions reporting current populations and reports of successful reproductions within the last 12 months, were downloaded. The completeness of the data in ZIMS cannot be guaranteed, as it is updated continuously, some entries may be outdated and not all zoos use ZIMS for population data. Data about offspring is only available for the previous 12 months. Since juvenile individuals are subsequently listed as adults, the breeding success of past years is also reflected in the number of adults of each species.

To analyse additional populations, the website Zootierliste (Zoo Animal List: ZTL; Graf et al. 2021) was checked for additional species entries. ZTL is a database in which current and former animal populations of European zoos and other public animal holdings are entered and updated by registered users. Since ZTL contains neither information on the number of individuals nor breeding success, all further analyses are based exclusively on data retrieved from ZIMS.

ZIMS entries for subspecies were assigned to those of the respective species. These were summed for the respective populations. To exclude possible duplication, all species were checked for synonyms using Avibase (Lepage 2022).

Conservation status

Extinction risk assessments and population trends for all species were downloaded in February and March 2022 from the IUCN Red List of Threatened Species (IUCN 2022).

Species were classified into three threat groups according to their status on the IUCN Red List. Species classified as Vulnerable (VU), Endangered (EN) or Critically Endangered (CR) were grouped as ‘threatened’ species. One species that was evaluated as Extinct (EX) was also included in the threatened group. Least Concern (LC) and Near Threatened (NT) were grouped as ‘not threatened’ species. The third group ‘no data’ includes species that were listed as Data Deficient (DD) or Not Evaluated (NE). None of the species listed in ZIMS were assessed as Extinct in the Wild (EW), so this category was not assigned to any group. For a detailed analysis and comparison of the threat to zoo-kept species compared to species globally, the three threat groups were presented in their original categories.

ZIMS records that were only designated at genus level were not included, because IUCN Red List status is only given at species level; genera records could represent different threat levels.

Data were compiled in Microsoft Excel and further analysed via the statistical program R version 4.1.2 (R Core Team 2021) and the R packages ‘dplyr’ (Wickham et al. 2021) and ‘gtools’ (Warnes et al. 2021). The packages ‘ggplot2’ (Wickham 2016), ‘ggpattern’

(Davis and Mike 2022), 'ggrepel' (Slowikowski 2021) and 'scales' (Wickham and Seidel 2020) were used for visualisation of plots. The distribution characteristics (e.g. number of holdings, number of individuals) between threatened and non-threatened species were examined for deviations from randomness. For this purpose, 10,000 random sample sets were drawn from the available zoo data in R and 99% confidence intervals for the randomised occurrence of the distribution characteristic were calculated (bootstrap approach). This was to check whether for example threatened species are kept in significantly more institutions than would have been expected from a random distribution across all species kept (threatened and not threatened). This determines whether there is a clear focus of zoos on threatened species.

Results

Distribution of records

Of the 408 passerine bird species listed only in ZIMS, the IUCN assessed 15 as threatened (including one species assessed as EX), 386 as not threatened and seven were not assessed (Figure 1). On the ZTL another 57 species were listed of which 52 were assessed as not threatened and the remaining five were not assessed. The 422 species represented in both databases consisted of 20 threatened species, 400 non-threatened species and two unassessed species.

ZIMS reported 5,743 passerine bird holdings (for each zoo, each species kept was counted as one holding): 2,873 in European zoos, 1,657 in North American zoos, 541 in Asian zoos, 377 in Australian zoos, 213 in South American zoos and 82 in African zoos (Figure 2). With 418 species, European zoos kept the largest number of species, followed by North America (335), Asia (255), Australia (145), South America (112) and Africa (63). Fourteen threatened species were kept in European zoos, 11 in North American zoos, 22 in Asian zoos, six in Australian zoos, five in South American zoos and one in African zoos. Four unassessed species were kept by North American zoos, three by European zoos, two by Australian zoos and one by Asian zoos (Figure 3).

Phylogenetic representation

The 830 passerine bird species currently recorded in ZIMS represent only about 13.7% of the 6,041 known passerine bird species (Winkler et al. 2015). Of the 137 families, 79 (57.7%) are represented by at least one species in ZIMS institutions (Figure 4a–b). Of the 1,348 genera listed, 354 (26.3%) were represented by at least one species in zoos. The most species-rich family of Tyrannidae was represented by only six species in zoos (1.5% of 410 listed species).

Distribution of passerine birds in IUCN Red List categories

A total of 92.1% of the species kept in zoos were assessed as Least Concern (Figure 5a), with a further 2.7% listed as Near Threatened (94.7% (786) non-threatened species). A total of 4.1% (34 species) were assessed as threatened (1.5% Vulnerable, 1.7% Endangered and 1% Critically Endangered). Only 1.1% (9 species) were not yet assessed or could not be found on the IUCN Red List. One species (*Zosterops conspicillatus*) listed in two North American institutions was assessed as Extinct. Currently kept threatened species, their individual and holding numbers and number of offspring are listed in Table 1.

The IUCN (2022) currently lists 6,659 assessed passerine bird species (Figure 5b), 81% (5,393 species) of which are classified as Least Concern and 7.9% (524) as Near Threatened (88.9% non-threatened species). The 9.8% threatened species consist of 5.3% (354) species classified as Vulnerable, 3.2% (212) as Endangered and 1.32% (88) as Critically Endangered. Only 0.4% (27) species are still assessed as Data Deficient. One species (0.02%; *Corvus hawaiiensis*) is classified as Extinct in the Wild. A total of 60 (0.9%) species are listed as Extinct.

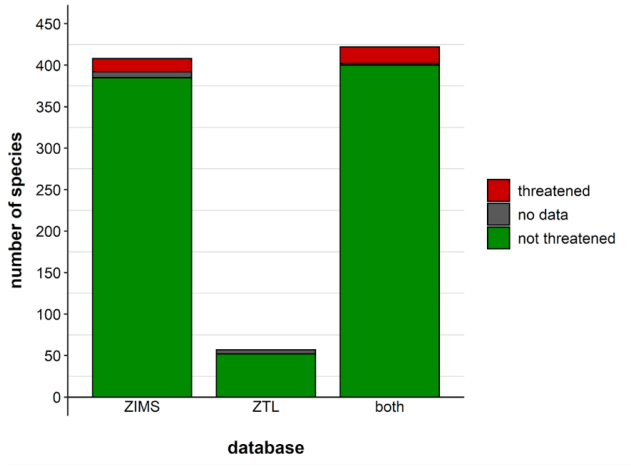

Figure 1. Number of passerine bird species (n = 887) listed only in one of two databases (ZIMS (2021) or ZTL (Graf et al. 2021)) and species listed in both. The columns are divided by colour, referring to the Red List Category of the species listed in each database according to the (IUCN 2022): no data: all species listed as Data Deficient or Not Evaluated; not threatened: all species listed as Near Threatened or Least Concern; threatened: all species listed as Vulnerable, Endangered or Critically Endangered. 408 Species are listed only in ZIMS, 57 only on the ZTL and 422 species are listed in both databases.

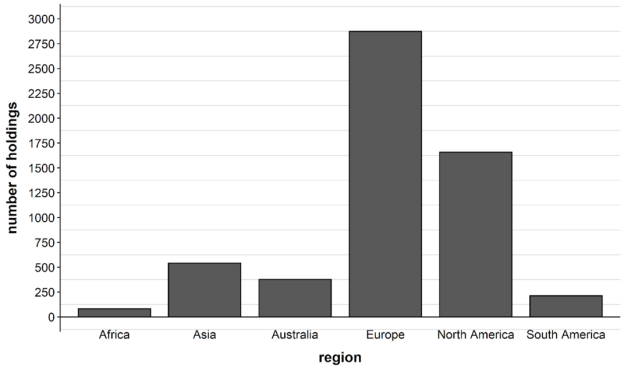

Figure 2. Number of passerine bird holdings in each zoo-region as reported in ZIMS (2021). Every species in a zoo is counted as one holding. Therefore, zoos keeping more than one species are counted multiple times. The region labelled as Australia comprises the continental region of Australia and Oceania.

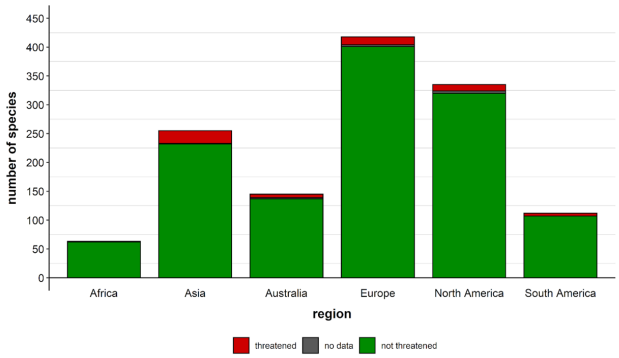

Figure 3. Number of different passerine bird species kept in each zoo-region as reported in ZIMS (2021). The columns are divided by colour, referring to the Red List Category of the species according to the (IUCN 2022): no data: all species listed as Data Deficient or Not Evaluated; not threatened: all species listed as Near Threatened or Least Concern; threatened: all species listed as Vulnerable, Endangered or Critically Endangered. The region labelled as Australia comprises the continental region of Australia and Oceania.

Breeding success in zoos

A total of 24.3% of the species kept were reported to have bred successfully in the period from November 2020 to November 2021 (Table 2). This includes 18 of the 35 threatened species (Figure 6), 183 of the 786 non-threatened species and one of the nine unassessed species. More threatened species were bred (8.9%) than would be expected from a random selection of the 830 passerine bird species (P<0.01, 99% CI 4.19–4.26%). Of the 51.4% of threatened species that bred, 22.9% bred in one zoo, 8.6% in 2–4 zoos, 11.4% in 5–10 zoos, 2.9% in 11–20 zoos and 5.71% in 21–31 zoos (Figure 7). The one unclassified species (*Lichenostomus cassidix*) was bred in only one zoo. Of the 23.3% of non-threatened species that bred, 9.8% bred in one zoo, 7.6% in 2–4 zoos, 4.5% in 5–10 zoos, 1.2% in 11–20 zoos and 0.3% in 21–31 zoos.

Number of holdings for each threat group

Eleven of the 35 threatened species (31.4%) were kept by only one zoo (Figure 8), ten (28.6%) threatened species by 2–4 zoos, six (17.1%) by 5–10 zoos and three (8.6%) by 11–25 zoos. Five threatened species (14.3%) were kept in more than 25 zoos: *Liocichla omeiensis* (27), *Garrulax bicolor* (29), *Garrulax courtoisi* (54), *Lonchura oryzivora* (126) and *Leucopsar rothschildi* (172 institutions, the highest number overall). Threatened species were kept in significantly more institutions than would be expected by chance (P<0.01, 99% CIs: single 39.58–40%, 2–4 zoos 30.91–31.31%, 5–10 zoos 11.96–12.24%, 11–25 zoos 11.06–11.33%, >25 zoos 5.71–5.91%). Of the 786 non-threatened species, 312 were kept in only one zoo (39.8%), 248 species (31.6%) in 2–4 zoos, 92 species by 5–10 zoos (11.7%), 90 species by 11–25 zoos (11.5%) and 43 species in more than 25 zoos (5.5%). Of the nine unassessed species six were kept in only one zoo (66.6%), one species in 2–4 zoos (11.1%) and two species in 5–10 zoos (22.2%).

Distribution of individuals

ZIMS institutions have registered 44,394 passerine bird individuals (27.1% males, 23.2% females, 49.7% unsexed). For 143 species, only a single individual is kept in ZIMS institutions: six threatened species, 136 non-threatened and one unassessed. More than half (56.5%) of the species are represented by fewer than ten individuals (including species of which only a single individual is kept): 12 threatened species, 450 non-threatened and 7 unassessed (Figure 9). For 26% of the species (12 threatened, 202 non-threatened, two unassessed) between 10 to 49 individuals are kept. For 7.2% of species, 50 to 99 individuals (two threatened, 58 non-threatened) are kept and for 7.3% of species 100 to 299 individuals (seven threatened, 54 non-threatened) are kept. A total of 1.1% of the species were represented with 300–499 individuals: all nine non-threatened species. For 1.8% of species more than 500 individuals were kept: two threatened species (*Leucopsar rothschildi*, 866 individuals; *Lonchura oryzivora*, 3,014) and 13 non-threatened species (*Lonchura punctulata*, 501; *Serinus canaria*, 525; *Aplonis panayensis*, 536; *Passerina ciris*, 611; *Foudia madagascariensis*, 721; *Lamprotornis superbus*, 726; *Quelea quelea*, 782; *Pycnonotus jocosus*, 850; *Taeniopygia castanotis*, 960; *Ploceus castaneiceps*, 1,199; *Chloebia gouldiae*, 1,466; *Ploceus cucullatus,* 1,667; *Taeniopygia guttata,* 5,084). Individual-rich species were significantly more frequent among threatened species than would be expected from a random distribution (P<0.01, 99% CIs: <10 individuals 56.21–56.63%, 10–49 individuals 25.87–26.24%, 50–99 individuals 7.17–7.39%, 100–299 individuals 7.21–7.44%, 300–499 individuals 1.05–1.14%, >500 individuals 1.77–1.88%).

Discussion

The proportion of all passerine bird species held in ZIMS institutions represents a small fraction of the passerine bird species listed on the IUCN Red List (6,659 species as of April 2022), at about 12.5%. Even if additional species are found in zoos not contributing to ZIMS, this would likely only result in a slight increase (e.g. including ZTL: 13.3%). Furthermore, new bird species continue to be discovered, or existing taxa are reclassified, which is already reflected by the difference in species numbers stated by Winkler et al. (2015) and current Red List data (IUCN 2022). Current estimates suggest there are up to 18,000 bird species worldwide, including cryptic and undiscovered species (Barrowclough et al. 2016). On the one hand, this could mean that the proportion of species kept in zoos is even lower than calculated with the current data. On the other hand, the species kept in zoos, if not yet genetically studied, could also contain cryptic species and thus lead to a higher number of songbird species in zoos.

About 58% of all songbird families are represented by at least one species in zoos. Of all genera, only about 26% are kept. The songbird family that includes the largest number of different species in zoos, the Thraupidae, are a very colourful group, a characteristic that many visitors find attractive (Carr 2016; Colléony et al. 2017).

Nearly 95% of the passerine bird species held in ZIMS institutions are non-threatened species and thus are currently of little relevance for ex situ conservation of threatened species. Compared to the distribution of IUCN categories of all songbird species, non-threatened species currently account for a larger proportion in ZIMS institutions than among songbirds in general (~89%). Thus, there is currently no general trend toward keeping

Table 1. Threatened passerine bird species kept in ZIMS (2021) institutions (n = 35). Individuals: Number of kept individuals: M: male, F: female, U: unsexed. IUCN: IUCN Red List Category (2022). Pop. Trend: Population Trend (IUCN 2022): ↓ decreasing, ↑ increasing, → stable, ? unspecified. Offspring in the past 12 Month. Breeding Inst: Number of Institutions which reported Offspring.

Family	Species	Individuals (M/F/U)	Institution	IUCN	Population trend	Offspring	Breeding Institution
Cotingidae	*Cephalopterus penduliger*	3 (3/0/0)	2	VU	↓	0	0
	Procnias tricarunculata	2 (0/2/0)	1	VU	↓	0	0
Dasyornithidae	*Dasyornis brachypterus*	22 (12/8/2)	1	EN	↓	5	1
Meliphagidae	*Anthochaera phrygia*	167 (81/72/14)	9	CR	↓	45	5
Corvidae	*Cissa thalassina*	101 (42/48/11)	9	CR	↓	9	4
	Garrulus lidthi	13 (4/2/7)	1	VU	↓	0	0
	Pica nuttalli	1 (0/0/1)	1	VU	→	0	0
Callaeidae	*Callaeas cinereus*	1 (0/1/0)	1	CR	↓	0	0
Pycnonotidae	*Alophoixus bres*	5 (0/0/5)	1	EN	↓	0	0
	Pycnonotus zeylanicus	48 (10/8/30)	5	CR	↓	8	1
	Rubigula dispar	19 (7/7/5)	4	VU	↓	2	1
Zosteropidae	*Cleptornis marchei*	23 (14/9/0)	10	EN	↓	0	0
	Zosterops conspicillatus	18 (14/4/0)	2	EX	?	1	1
	Zosterops flavus	44 (7/6/31)	1	EN	↓	5	1
Leiothrichidae	*Garrulax bicolor*	139 (72/59/8)	29	EN	↓	33	10
	Garrulax rufifrons	34 (17/15/2)	3	CR	↓	0	0
	Garrulax courtoisi	260 (140/118/2)	54	CR	↓	41	13
	Liocichla omeiensis	91 (40/40/11)	27	VU	↓	40	8
Sturnidae	*Gracupica jalla*	30 (11/13/6)	2	CR	↓	4	1
	Leucopsar rothschildi	866 (383/374/109)	172	CR	↓	115	31
	Acridotheres javanicus	8 (0/0/8)	2	VU	↓	0	0
	Acridotheres melanopterus	92 (39/49/4)	5	EN	↓	0	0
Mimidae	*Toxostoma bendirei*	1 (0/0/1)	1	VU	↓	0	0
Turdidae	*Geokichla interpres*	108 (1/1/106)	2	EN	↓	0	0
Muscicapidae	*Copsychus sechellarum*	1 (1/0/0)	1	EN	↑	0	0
Chloropseidae	*Chloropsis cochinchinensis*	27 (14/9/4)	7	EN	↓	2	1
	Chloropsis sonnerati	44 (14/6/24)	4	EN	↓	5	1
Estrildidae	*Lonchura oryzivora*	3014 (211/189/2614)	126	EN	↓	222	22
Fringillidae	*Spinus cucullatus*	103 (36/31/36)	17	EN	↓	12	3
Emberizidae	*Emberiza rustica*	1 (1/0/0)	1	VU	↓	0	0
	Emberiza sulphurata	1 (0/0/1)	1	VU	↓	0	0
Icteridae	*Icterus oberi*	45(24/20/1)	16	VU	→	2	2
Thraupidae	*Sporophila frontalis*	4 (1/0/3)	2	VU	↓	0	0
	Sporophila maximiliani	5 (2/2/1)	2	EN	↓	0	0
	Gubernatrix cristata	109 (48/41/20)	14	EN	↓	27	6

more threatened passerine bird species. Many non-threatened species probably do not need ex situ intensively managed zoo populations. They are kept in zoos for entertainment or educational purposes, are easy to obtain and keep, have fascinating appearances (e.g. *Chloebia gouldiae*) or are used as flagship species to highlight problems. Of the three passerine bird species with the highest numbers of individuals in ZIMS institutions, two species (*Taeniopygia guttata, Chloebia gouldiae*) classified as LC

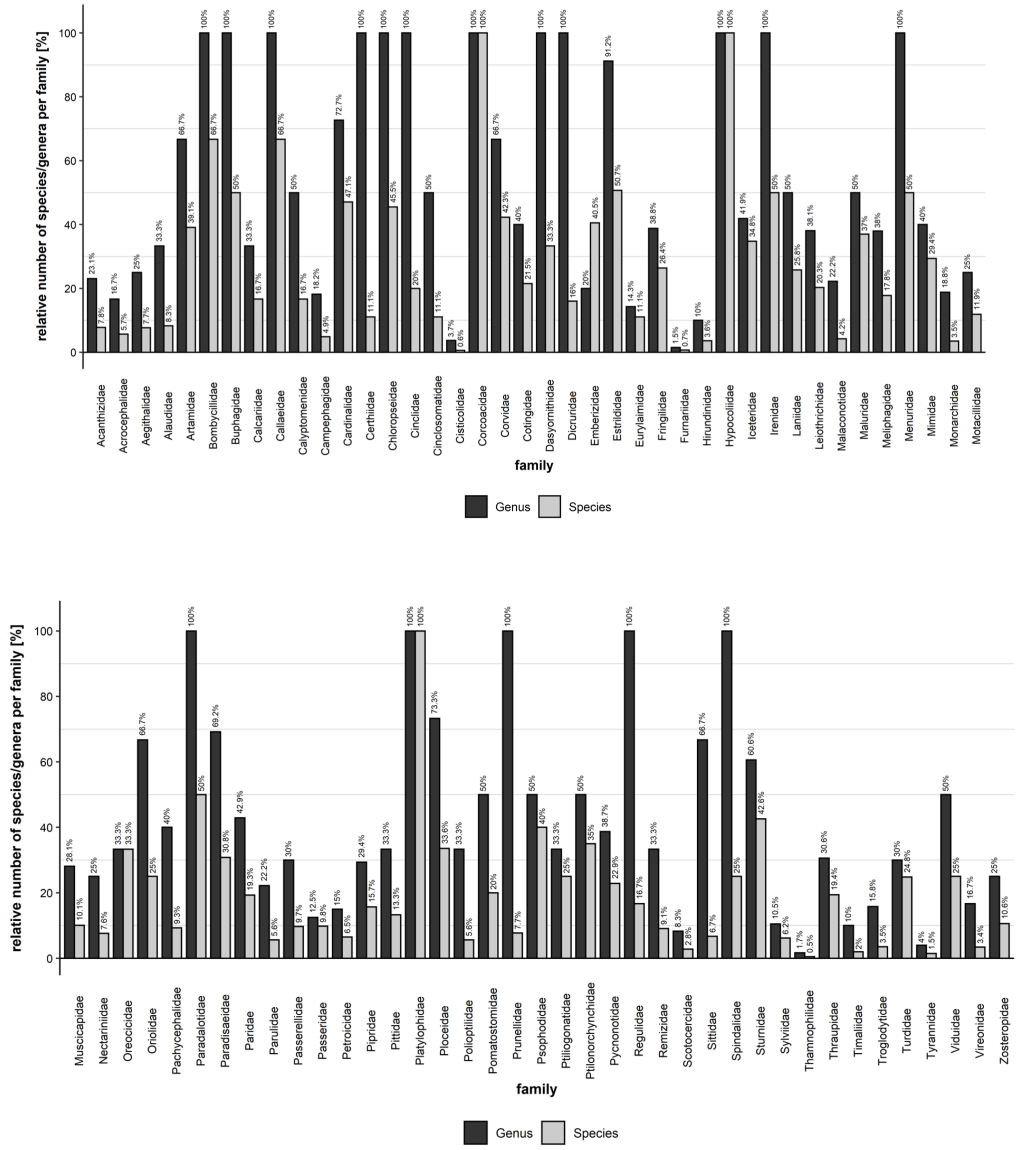

Figure 4. a. Relative number of species or genera listed in ZIMS (2021) from the currently described species/genera (Winkler et al. 2015) per family. The percentage of passerine bird genera (dark grey) and passerine bird species (light grey) kept in zoos of all described species or genera for each family. Only families of which at least one species is kept are shown. 4b. Relative number of species or genera listed in ZIMS (2021) from the currently described species/genera (Winkler et al. 2015) per family. The percentage of passerine bird genera (dark grey) and passerine bird species (light grey) kept in zoos of all described species or genera for each family. Only families of which at least one species is kept are shown.

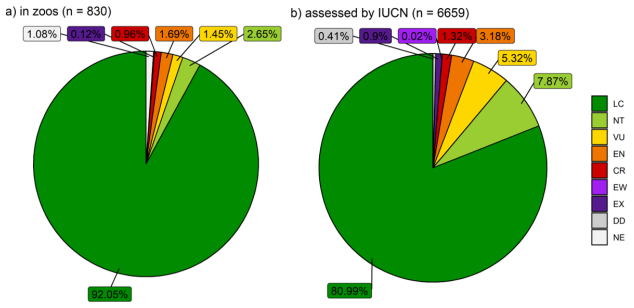

Figure 5. Distribution of IUCN Red List categories of a) passerine birds kept in zoos (n = 830; according to ZIMS (2021)) and b) passerine birds worldwide assessed by the IUCN (n = 6659; (IUCN 2022)).

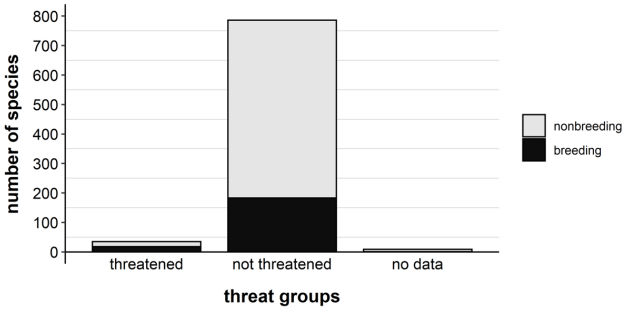

Figure 6. Number of passerine bird species with and without reported breeding success in ZIMS (2021) institutions within the last 12 months. Species are divided according to their IUCN Red List status (2022). Dark grey: species that have bred in the last 12 months; light grey: species that have not bred in the last 12 months.

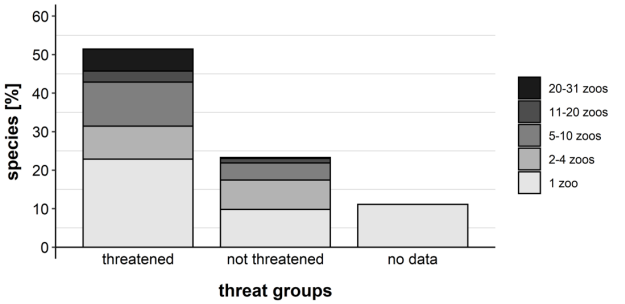

Figure 7. Percentage of passerine bird species with reported breeding success categorised by the number of ZIMS (2021) institutions that reported success. Breeding success was reported by only a single zoo, two to four zoos, five to ten zoos, eleven to twenty zoos or twenty to thirty-one zoos, as shown by the different shades of grey. The species are divided by the three threat groups according to their IUCN (2022) Red List status. The percentages were calculated by dividing the total number of species for a threat group by the number of species in that threat group with reported breeding success for each size group of zoo-keeping numbers.

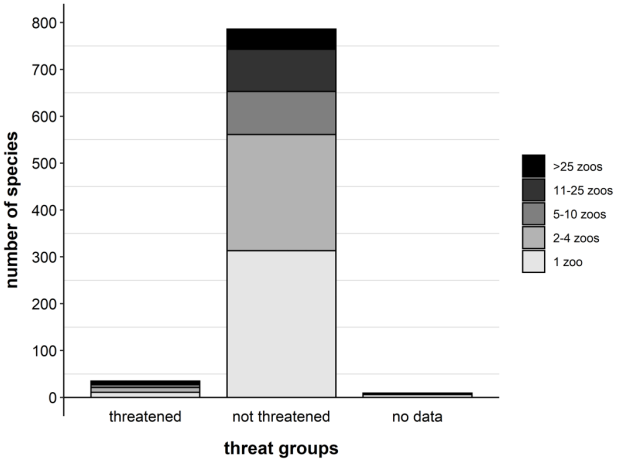

Figure 8. Classification of passerine bird species according to the number of holding ZIMS (2021) institutions. The species are divided by the three threat groups according to their IUCN (2022) Red List status. For each threat group, the passerine bird species were subdivided according to the number of ZIMS institutions holding them, represented by the different shades of grey.

are regularly found as pets. These species are not dependent on zoos and the space they occupy could instead benefit highly threatened species.

By far, most passerine bird enclosures are in European and North American zoos. While ZIMS institutions are mainly located in temperate regions (ZIMS 2021), most threatened species originate from tropical areas (Grenyer et al. 2006; Hoffmann et al. 2010). For reintroduction programmes, it can be beneficial to have breeding institutions within a species' natural range. These can be used to breed and release the species, and as a stopover point to help animals introduced from other climates adjust to their natural habitat (Conde et al. 2011).

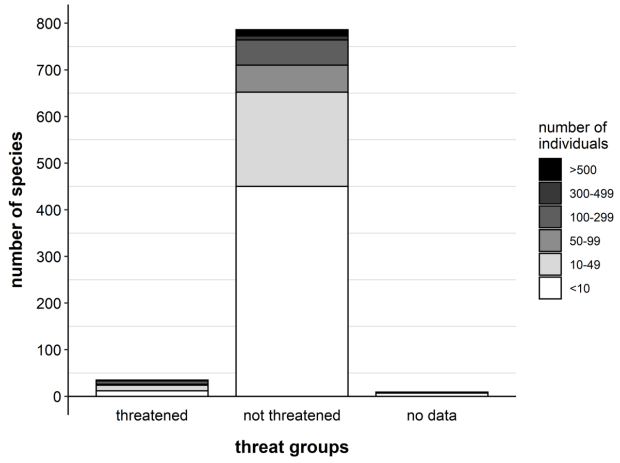

Figure 9. Number of individuals of passerine bird species kept in ZIMS (2021) institutions (n = 830). The species are divided by the three threat groups according to their IUCN (2022) Red List status. The greyscale shows the number of species that fall within the range of the number of individuals.

Of the 654 passerine bird species listed as threatened by the IUCN, only 5.3% are held in ZIMS institutions. Thus, for the majority of threatened species, there are currently no ex situ backup populations. Of the threatened species held, about half (51.4%) have been bred in 2020–2021, of which 38.9% have been bred in at least five zoos. With this reproductive success, a good foundation has been laid, as not all species may currently be in reproductive groups in zoos. However, nearly one-third (31.4%) of threatened species are held in only one institution. Single zoos dedicated to keeping threatened birds can use their expertise to keep more challenging threatened birds. Such specialised breeding facilities can form starting points for breeding networks by providing offspring to other suitable facilities. With an expansion of zoos or zoo associations dedicated to such tasks, the number of threatened species in zoos could be increased. Keeping species in multiple institutions can increase ex situ population size and diversity. Spreading populations across multiple institutions serves as a backup in case of unpredictable events, leading to better protection of the entire population.

Overall, populations of threatened species kept in zoos are rather small. More than one third (34.3%) of populations in ZIMS institutions are of less than 10 individuals. Simply having several different sexed individuals in a zoo does not promise successful breeding, as the animals may be too young or old, not kept together or incompatible for other reasons. Therefore, the numbers of individuals of a species does not indicate the number of available reproductive pairs. All threatened species kept in more than 25 zoos are part of a studbook or programme, except *Lonchura oryzivora* which, however, has by far the highest number of individuals (3,014). Three of these threatened species

Table 2. Passerine bird species kept in ZIMS (2021) institutions with reported Offspring in the last 12 months (n = 202). IUCN: IUCN Red List Category (2022). Offspring in the past 12 Month. Breeding Inst: Number of Institutions which reported Offspring.

Family	Species	IUCN	Offspring	Breeding Institutions
Pittidae	*Pitta sordida*	LC	7	1
	Pitta versicolor	LC	4	1
Cotingidae	*Rupicola peruvianus*	LC	10	4
	Rupicola rupicola	LC	5	2
	Cotinga cayana	LC	3	1
	Xipholena punicea	LC	4	2
Ptilonorhynchidae	*Ailuroedus buccoides*	LC	1	1
	Ailuroedus crassirostris	LC	5	1
	Ptilonorhynchus violaceus	LC	1	1
	Sericulus chrysocephalus	LC	3	1
Maluridae	*Malurus coronatus*	LC	4	1
	Malurus cyaneus	LC	3	1
	Malurus lamberti	LC	4	1
	Malurus splendens	LC	3	2
Dasyornithidae	*Dasyornis brachypterus*	EN	5	1
Meliphagidae	*Certhionyx variegatus*	LC	3	1
	Meliphagidae	LC	13	3
	Lichenostomus cassidix	NE	23	1
	Lichenostomus melanops	LC	13	1
	Anthochaera phrygia	CR	45	5
	Myzomela sanguinolenta	LC	1	1
	Melithreptus lunatus	LC	6	2
	Entomyzon cyanotis	LC	32	13
Oriolidae	*Oriolus chinensis*	LC	3	2
	Oriolidae	LC	3	2
Oreoicidae	*Oreoica gutturalis*	LC	4	1
Cinclosomatidae	*Cinclosoma cinnamomeum*	LC	1	1
Psophodidae	*Psophodes occidentalis*	LC	3	1
	Psophodes olivaceus	LC	11	4
Timaliidae	*Pomatorhinus montanus*	LC	3	1
Timaliidae	*Pomatorhinus montanus*	LC	3	1
Artamidae	*Artamus leucorynchus*	LC	37	5
	Artamidae	LC	2	1
Malaconotidae	*Laniarius barbarus*	LC	1	1
Laniidae	*Urolestes melanoleucus*	LC	6	2
	Laniidae	NT	82	3
	Lanius cabanisi	LC	1	1
Corvidae	*Pyrrhocorax pyrrhocorax*	LC	42	5
	Urocissa erythroryncha	LC	58	19
	Cissa thalassina	CR	9	4
	Cyanopica cyanus	LC	42	13
	Corvus albus	LC	6	2
	Corvus corax	LC	17	4
	Corvus frugilegus	LC	2	1
	Cyanocitta cristata	LC	7	1
	Cyanocorax chrysops	LC	19	5
	Cyanocorax yncas	LC	4	3
Paradisaeidae	*Paradisaea minor*	LC	3	2
	Paradisaea raggiana	LC	27	9
	Paradisaea rubra	NT	5	2
Callaeidae	*Philesturnus rufusater*	NT	2	1
Alaudidae	*Panurus biarmicus*	LC	30	5
Pycnonotidae	*Hypsipetes leucocephalus*	LC	16	3
	Spizixos semitorques	LC	13	4
	Pycnonotus zeylanicus	CR	8	1
	Rubigula dispar	VU	2	1
	Pycnonotus cafer	LC	6	1
	Pycnonotus jocosus	LC	102	17
	Pycnonotus barbatus	LC	7	2
	Pycnonotus leucotis	LC	9	2
	Pycnonotus bimaculatus	NT	2	1
Zosteropidae	*Zosterops conspicillatus*	EX	1	1
	Zosterops eurycricotus	LC	2	1
	Zosterops flavus	EN	5	1

Table 2. Continued.

Family	Species	IUCN	Offspring	Breeding Institutions
Leiothrichidae	*Garrulax bicolor*	EN	33	10
	Garrulax leucolophus	LC	26	6
	Garrulax palliatus	NT	2	2
	Garrulax maesi	LC	1	1
	Garrulax canorus	LC	7	3
	Pterorhinus chinensis	LC	4	2
	Garrulax courtoisi	CR	41	13
	Leiothrix argentauris	LC	20	4
	Leiothrix lutea	LC	51	9
	Liocichla omeiensis	VU	40	8
	Liocichla steerii	LC	1	1
	Liocichla ripponi	LC	20	4
Sturnidae	*Gracupica nigricollis*	LC	12	4
	Sturnia pagodarum	LC	34	9
	Spodiopsar sericeus	LC	6	1
	Sturnia sinensis	LC	20	7
	Sturnus vulgaris	LC	17	7
	Gracupica jalla	CR	4	1
	Leucopsar rothschildi	CR	115	31
	Acridotheres ginginianus	LC	13	1
	Onychognathus morio	LC	25	3
	Lamprotornis caudatus	LC	3	1
	Lamprotornis iris	LC	20	7
	Lamprotornis purpureus	LC	17	5
	Lamprotornis purpuroptera	LC	1	1
	Lamprotornis superbus	LC	127	24
	Lamprotornis regius	LC	29	7
	Cinnyricinclus leucogaster	LC	16	6
	Sarcops calvus	LC	1	1
	Gracula religiosa	LC	12	4
	Ampeliceps coronatus	LC	18	5
	Scissirostrum dubium	LC	92	12
	Aplonis metallica	LC	69	5
	Aplonis panayensis	LC	26	5
Turdidae	*Hylocichla mustelina*	LC	2	1
	Catharus ustulatus	LC	5	1
	Geokichla citrina	LC	10	3
	Geokichla dohertyi	NT	47	13
	Turdus dissimilis	LC	1	1
	Turdus merula	LC	1	1
	Turdus pallidus	LC	7	1
	Turdus philomelos	LC	1	1
Muscicapidae	*Copsychus saularis*	LC	24	4
	Copsychus malabaricus	LC	72	14
	Cossypha albicapillus	LC	24	10
	Cossypha caffra	LC	4	1
	Cossypha niveicapilla	LC	40	8
	Cichladusa guttata	LC	5	1
Bombycillidae	*Bombycilla cedrorum*	LC	7	1
	Bombycilla garrulus	LC	2	1
Irenidae	*Irena puella*	LC	37	8
Chloropseidae	*Chloropsis cochinchinensis*	EN	2	1
	Chloropsis sonnerati	EN	5	1
Nectariniidae	*Chalcomitra senegalensis*	LC	2	1
	Cinnyris coccinigastrus	LC	2	1
Ploceidae	*Dinemellia dinemelli*	LC	19	6
	Euplectes afer	LC	41	5
	Foudia madagascariensis	LC	58	5
	Philetairus socius	LC	1	1
	Ploceus castaneiceps	LC	31	9
	Ploceus cucullatus	LC	136	15
	Ploceus melanocephalus	LC	4	1
	Ploceus nigricollis	LC	2	1
	Ploceus velatus	LC	4	1
	Quelea quelea	LC	326	3
Estrildidae	*Lagonosticta senegala*	LC	63	3
	Pytilia hypogrammica	LC	5	1
	Granatina ianthinogaster	LC	2	2
	Uraeginthus bengalus	LC	13	3
	Uraeginthus cyanocephalus	LC	3	1
	Estrilda astrild	LC	15	2

Family	Species	IUCN	Offspring	Breeding Institutions
Estrildidae	*Amandava amandava*	LC	13	3
	Spermestes bicolor	LC	1	1
	Spermestes fringilloides	LC	11	1
	Lonchura striata	LC	18	2
	Lonchura punctulata	LC	15	2
	Lonchura flaviprymna	LC	5	1
	Lonchura castaneothorax	LC	10	4
	Lonchura oryzivora	EN	222	22
	Stagonopleura guttata	LC	36	9
	Neochmia temporalis	LC	15	2
	Neochmia phaeton	LC	13	1
	Bathilda ruficauda	LC	8	4
	Poephila acuticauda	LC	10	2
	Poephila cincta	LC	28	2
	Taeniopygia guttata	LC	139	12
	Taeniopygia castanotis	LC	228	6
	Erythrura tricolor	LC	23	3
	Erythrura trichroa	LC	4	1
	Erythrura psittacea	LC	6	2
	Chloebia gouldiae	NT	288	22
Motacillidae	*Motacilla alba*	LC	8	1
	Motacilla grandis	LC	7	1
Fringillidae	*Euphonia violacea*	LC	48	7
	Pyrrhula pyrrhula	LC	5	1
	Haemorhous mexicanus	LC	7	1
	Chloris sinica	LC	3	1
	Linaria cannabina	LC	3	1
	Loxia curvirostra	LC	8	2
	Serinus canaria	LC	54	4
	Spinus cucullatus	EN	12	3
Emberizidae	*Emberiza cioides*	LC	4	1
	Emberizidae	LC	1	1
	Emberiza schoeniclus	LC	8	1
Passerellidae	*Ammodramus savannarum*	LC	214	1
	Melospiza melodia	LC	8	1
Icteridae	*Psarocolius decumanus*	LC	3	3
	Psarocolius viridis	LC	11	2
	Cacicus cela	LC	19	6
	Cacicus haemorrhous	LC	8	1
	Icterus galbula	LC	2	1
	Icterus icterus	LC	19	6
	Icterus nigrogularis	LC	3	1
	Icterus oberi	VU	2	2
	Quiscalus quiscula	NT	1	1
	Chrysomus icterocephalus	LC	5	1
Cardinalidae	*Pheucticus ludovicianus*	LC	12	2
	Passerina ciris	LC	8	1
	Passerina rositae	NT	3	1
	Cardinalis cardinalis	LC	29	4
Thraupidae	*Chlorophanes spiza*	LC	22	3
	Sicalis flaveola	LC	10	3
	Volatinia jacarina	LC	21	2
	Coryphospingus cucullatus	LC	7	2
	Ramphocelus bresilius	LC	24	7
	Ramphocelus carbo	LC	15	5
	Cyanerpes caeruleus	LC	12	3
	Cyanerpes cyaneus	LC	15	5
	Tersina viridis	LC	3	2
	Coereba flaveola	LC	5	2
	Phonipara canora	LC	12	5
	Gubernatrix cristata	EN	27	6
	Paroaria coronata	LC	12	5
	Paroaria gularis	LC	26	4
	Stilpnia cayana	LC	3	1
	Stilpnia cyanicollis	LC	5	1
	Tangara gyrola	LC	4	1
	Tangara mexicana	LC	38	9
	Tangara velia	LC	6	2

also report the next highest numbers of individuals of threatened species. This shows the great potential of well-coordinated conservation breeding programmes in zoos and how they can build up large numbers of individuals through good networking. In this way, zoos can lay the foundation for future reintroductions.

Nearly all held threatened species show a negative population trend in the wild. Without rapid conservation measures in-situ, zoo populations could quickly become the last viable fragments of species populations. To keep zoo populations viable in the long term and to maintain the possibility for reintroductions in case of a further collapse of in-situ populations, sufficiently large and genetically diverse ex situ populations are important. Studbooks can be helpful to pair birds to maintain the most

diverse population possible. In total, 14 of the 35 threatened species (40%) are registered in a studbook in ZIMS (2021) (some with several studbooks, see Supplementary Table A1), while 54 studbooks exist for the 786 non-threatened species (6.9%). For three other threatened species, of which no individuals are listed in ZIMS, ZIMS lists studbooks. Thus, zoos' capacity to breed and keep threatened species should be further expanded, and breeding and networking among institutions optimised through studbooks to maintain diverse populations. Target population size will vary among species. By taking in individuals from the wild (e.g. from confiscations or rescued specimens) or exchanging them, and thus jointly protecting in-situ and ex situ populations according to the One Plan Approach, even a seemingly small population can be kept viable and contribute to the protection of a species.

A well-functioning implementation of the One Plan Approach is shown for the Javan green magpie *Cissa thalassina* (CR). After initial difficulties, a breeding programme was established at the Cikananga Conservation Breeding Center (CCBC) in Indonesia using individuals acquired primarily on bird markets. To reduce the risk of sole dependency on this backup population, a dozen animals were moved to European zoos in 2015 to establish an additional population. While the populations are now being protected and rebuilt in Europe and Indonesia, the CCBC is pushing ahead with research and measures on Java to reduce threats from the illegal bird trade and to re-establish safe in-situ habitats (Cikananga Wildlife Center 2023). In many cases, reintroduction of individuals at this time would be fruitless, especially in the case of songbirds that are victims of illegal wildlife trafficking, as they would be quickly hunted. This shows the importance of networking of different institutions, both locally and further afield, to build a comprehensive network for species conservation. Cooperation with local conservation institutions allows zoos to expand threatened species holdings without removing individuals from weakened in-situ populations. Current limitations to reintroduction might be overcome in future due to research and application of new techniques (Conde 2013), as was the case for migratory birds raised in captivity that needed to learn their migratory route (Ellis et al 2003).

A good example of an active species conservation project is the protection of the Bali myna *Leucopsar rothschildi,* classified as Critically Endangered since at least 1994 (IUCN 2022). The Bali myna is one of many Asian songbird species that are severely threatened by illegal poaching and cage bird trade (EAZA 2022b; IUCN 2022), despite being listed on CITES Appendix I (CITES 2023). Ex situ populations are well managed through a Species Survival Plan (SSP, Association of Zoos and Aquariums 2016) and studbooks (EEP, JAZA and AZA, see Table A1) and ZIMS now lists 866 individuals in 172 institutions worldwide (ZIMS 2021). There is a much larger network of ex situ populations than about a decade ago (280 birds in 74 European zoos in 2011; Collar et al. 2012), but in-situ populations continue to collapse due to poaching (IUCN 2022; Nijman et al. 2017). This demonstrates the importance of primarily creating a safe in-situ habitat prior to reintroduction campaigns and communicating species conservation locally to residents. By subsequently restocking the local populations with birds from breeding programmes, zoos can play their part in the One Plan Approach. In the future, involvement of licensed private keepers in conservation breeding of threatened bird species should be considered as part of citizen conservation projects (Citizen Conservation 2022).

One species (*Zosterops conspicillatus*), kept in two zoos in North America with 18 individuals, is listed as Extinct by the IUCN. Half of these individuals are listed as subspecies *Zosterops conspicillatus saypani*, which has been listed as a distinct species since 2016 (*Zosterops saypani*, NT; HBW and BirdLife International 2017; IUCN 2022). Since the subspecies formerly belonged to *Zosterops conspicillatus* (Slikas et al. 2000), it is likely that the remaining nine individuals also belong to *Zosterops saypani.* This shows the importance of knowing exactly which species are being kept, to allow species-specific breeding without the development of hybrids (Conde et al. 2011).

In general, zoos should strive to keep and breed more threatened bird species, as the current proportion of just under 5% of threatened passerine bird species in ZIMS institutions is very low. The large proportion of non-threatened species represents an enormous potential for expanding and improving conservation work for threatened species. Currently, zoos provide good ex situ conservation measures for a few species, but many others are neglected. A gradual shift to more threatened bird species offers zoos enormous potential to increase their contribution to species conservation. Lammers et al. (2022) recommend replacing non-threatened taxa with threatened taxa requiring similar husbandry conditions without major changes (e.g. of enclosures) where possible. Since some threatened passerine bird species do not present good zoo display characteristics in the traditional sense (e.g. being small, inconspicuous in appearance, nocturnal or very timid), they are not well suited for many zoos. For these species, scientifically managed zoos with a strong conservation and research focus are of great importance. By providing off-show enclosures for these threatened species, zoos can expand the network of conservation breeding of threatened species and thus better contribute to their protection.

Since species once extinct are lost, space in zoos should go to those that need it most. This would provide a chance for species to be saved if in-situ populations are wiped out. Nevertheless, a certain proportion of widely known species may be important as flagship species, as zoo guests' willingness to donate is usually higher for charismatic species (Colléony et al. 2017). By creating Regional Collection Plans such as that of the Passerine Taxon Advisory Group for EAZA zoos, zoos can collectively establish and maintain a common goal for each species (EAZA 2017).

The primary goal is to protect species in their natural habitat. The protection of natural habitats through in-situ measures is equally important to protect known and also possible undiscovered species. Due to the serious human impact on natural habitats, in-situ measures are not sufficient for some species because their habitat is disappearing too fast and they are too threatened (Conde 2013). In such cases, ex situ holdings by zoos are of great importance to ensure the survival of a population, while in-situ measures are taken to restore or protect the habitat. Ex situ measures should therefore always complement in-situ measures (Glowka et al. 1994). This is a good opportunity for zoos, in addition to conservation breeding and possible reintroductions, to raise funds for local projects in the species' range countries through campaigns and to raise awareness of threats (Conde et al. 2011; Fa et al. 2014; Gusset and Dick 2010). In addition to ex situ actions in the species' range countries, institutions in other countries can also be of great importance as they can provide backup populations in case of catastrophic events (Jacken et al. 2020). Thus, cooperation among zoos (Conde 2013) and between zoos and institutions in species' range countries are also particularly important to ensure optimal success in working together to fulfil the One Plan Approach.

Acknowledgements

This study and the drafting of the manuscript was made possible by funds from the Verband der Zoologischen Gärten (VdZ) e.V. AG Wissenschaft und Forschung in the frame of the VdZ research plan (VdZ Forschungsplan), and with support from Cologne Zoo. The authors would like to thank two anonymous reviewers for their valuable suggestions.

References

Association of Zoos and Aquariums (2016) A*nimal Program Database: Bali Myna SSP.* Association of Zoos and Aquariums. Available online at https://ams.aza.org/eweb/DynamicPage.aspx?webcode=APProfile&key=1291a4f0-0fd7-4daf-a4f5-4b916095b7ae&ap1_key=1291a4f0-0fd7-4daf-a4f5-4b916095b7ae&ap1_pt1_key=92bae3e8-3e14-4373-80ca-4b6995704dc6

Barongi R., Fisken F.A., Parker M., Gusset M. (eds.). (2015) *Committing to Conservation: The World Zoo and Aquarium Conservation* Strategy. Gland, Switzerland: WAZA Executive Office.

Barrowclough G.F., Cracraft J., Klicka J., Zink R.M. (2016) How many kinds of birds are there and why does it matter? *PloS ONE* 11(11): e0166307. doi:10.1371/journal.pone.0166307

BirdLife International (2022a) *State of the World´s Birds–Species Dashboard.* https://datazone.birdlife.org/species/dashboard

BirdLife International (2022b) *BirdLife Data Zone: Many Bird Species are Close to Extinction.* https://datazone.birdlife.org/sowb/state/theme4 (Accessed 6 October 2022).

Byers O., Lees C., Wilcken J., Schwitzer C. (2013) The One Plan Approach: The philosophy and implementation of CBSG's approach to integrated species conservation planning. *WAZA Magazine* 14: 2–5.

Carr N. (2016) An analysis of zoo visitors' favourite and least favourite animals. *Tourism Management Perspectives* 20: 70–76. doi:10.1016/j.tmp.2016.07.006

Ceballos G., Ehrlich P.R., Dirzo R. (2017) Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *PNAS* 114(30): E6089–E6096. doi:10.1073/pnas.1704949114

Cikananga Wildlife Center (2023) *Javan Green Magpie – Cikananga Wildlife Center*. https://www.cikanangawildlifecenter.com/javan-green-magpie (Accessed 16 July 2023).

CITES (2023) *Convention on International Trade in Endangered Species of Wild Fauna and Flora.* Appendices I, II and III. Available online at https://cites.org/eng/app/appendices.php

Citizen Conservation (2022) *Citizen Conservation.* https://citizen-conservation.org/ (Accessed 12 September 2022).

Collar N.J., Gardner L., Jeggo D.F., Marcordes B., Owen A., Pagel T., Pes T., Vaidl A., Wilkinson R., Wirth R. (2012) Conservation breeding and the most threatened birds in Asia. *BirdingASIA* 18: 50–57.

Colléony A., Clayton S., Couvet D., Saint Jalme M., Prévot A.C. (2017) Human preferences for species conservation: Animal charisma trumps endangered status. *Biological Conservation* 206: 263–269. doi:10.1016/j.biocon.2016.11.035

Conde D.A., Flesness N., Colchero F., Jones O.R., Scheuerlein A. (2011) An emerging role of zoos to conserve biodiversity. *Science* 331(6023): 1390–1391. doi:10.1126/science.1200674

Conde D.A. (2013) Role of zoological gardens. In: MacLeod N., Archibald J.D., Levin P. (eds.). *Grzimek's Animal Encyclopedia: Extinction.* Farmington Hills, Missouri: Gale Cengage Learning, 207–215.

Davis T.L., Mike F.C. (2022) g*gpattern: 'ggplot2' Pattern Geoms*. Version R package version 0.4.2. Available online at https://CRAN.R-project.org/package=ggpattern

Donoso I., Sorensen M.C., Blendinger P.G., Kissling W.D., Neuschulz E.L., Mueller T., Schleuning M. (2020) Downsizing of animal communities triggers stronger functional than structural decay in seed-dispersal networks. *Nature Communications* 11(1): 1582. doi:10.1038/s41467-020-15438-y

EAZA (2017) *TAG Reports 2017.* Amsterdam, Netherlands: European Association of Zoos and Aquaria. Available online at https://www.eaza.net/assets/Uploads/Annual-report/1035-TAG-reports-2017-web.pdf

EAZA (2022a) *About Silent Forest*. https://www.silentforest.eu/about/ (Accessed 7 September 2022).

EAZA (2022b) *Bali Myna Fieldwork: Improving the Introduction and Monitoring Methods.* https://www.silentforest.eu/in-situ-projects/evaluating-methods-sites-and-needs-for-the-successful-reintroduction-of-the-bali-myna/ (Accessed 7 September 2022).

Ellis D.H., Sladen W.J.L., Lishman W.A., Clegg K.R., Duff J.W., Gee G.F., Lewis J.C. (2003) Motorized migrations: The future or mere fantasy? *Bioscience* 53(3): 260–264. doi:10.1641/0006-3568(2003)053[0260:MMTFOM]2.0.CO;2

Fa J.E., Gusset M., Flesness N., Conde D.A. (2014) Zoos have yet to unveil their full conservation potential. *Animal Conservation* 17(2): 97–100. doi:10.1111/acv.12115

García D., Martínez D. (2012) Species richness matters for the quality of ecosystem services: A test using seed dispersal by frugivorous birds. *Proceedings of the Royal Society B* 279(1740): 3106–3113. doi:10.1098/rspb.2012.0175

Gaston K.J., Cox D.T.C., Canavelli S.B., García D., Hughes B., Maas B., Martínez D., Ogada D., Inger R. (2018) Population abundance and ecosystem service provision: The case of birds. *BioScience* 68(4): 264–272. doi:10.1093/biosci/biy005

Glowka L., Burhenne-Guilmin F., Synge H., McNeely J.A., Gündling L. (1994) Article 9. Ex-situ conservation. In: *A Guide to the Convention on Biological Diversity.* Gland, Switzerland: IUCN, 52–56.

Graf R., Pfleiderer J., Fritsche M., Schmidt J., Mantei R., Peter S.P., Spangenberg F. (2021) *Zootierliste*. https://www.zootierliste.de/ (Accessed 7 April 2022).

Grenyer R., Orme C.D.L., Jackson S.F., Thomas G.H., Davies R.G., Davies T.J., Jones K.E., Olson V.A., Ridgely R.S., Rasmussen P.C., Ding T.S., Bennett P.M., Blackburn T.M., Gaston K.J., Gittleman J.L., Owens I.P.F. (2006) Global distribution and conservation of rare and threatened vertebrates. *Nature* 444(7115): 93–96. doi:10.1038/nature05237

Gusset M., Dick G. (2010) 'Building a future for wildlife'? Evaluating the contribution of the world zoo and aquarium community to in situ conservation. *International Zoo Yearbook* 44(1): 183–191.

Gusset M., Dick G. (2011) The global reach of zoos and aquariums in visitor numbers and conservation expenditures. *Zoo Biology* 30(5): 566–569. doi:10.1002/zoo.20369

HBW and BirdLife International (2017) *Handbook of the Birds of the World and BirdLife International Digital Checklist of the Birds of the World*. Available online at https://datazone.birdlife.org/species/taxonomy

Hoffmann M., Hilton-Taylor C., Angulo A., Böhm M., Brooks T.M., Butchart S.H.M. et al. (2010) The impact of conservation on the status of the world's vertebrates. *Science* 330(6010): 1503–1509.

IPBES (2019) Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Bonn, Germany: IPBES Secretariat.

IUCN (2022) *Red List of Threatened Species* (Version 2021-3). Available online at https://www.iucnredlist.org/ (Accessed 7 April 2022).

Jacken A., Rödder D., Ziegler T. (2020) Amphibians in zoos: A global approach on distribution patterns of threatened amphibians in zoological collections. *International Zoo Yearbook* 54(1): 146–164. doi:10.1111/izy.12272

Lammers R., Scholten C., Marcordes B., Pagel T.B., Rödder D., Ziegler T. (2022) Malagasy birds in zoological gardens – An analysis of zoo databases as basis for improved ex situ conservation measures. *Der Zoologische Garten* 90(2): 121–150. doi:10.53188/zg006

Lepage D. (2022) *Avibase–The World Bird Database*. https://avibase.bsc-eoc.org/avibase.jsp (Accessed 12 April 2022).

Melo M., Freitas B., Verbelen P., da Costa S.R., Pereira H., Fuchs J., Sangster G., Correia M.N., de Lima R.F., Crottini A. (2022) A new species of scops-owl (Aves, Strigiformes, Strigidae, *Otus*) from Príncipe Island (Gulf of Guinea, Africa) and novel insights into the systematic affinities within Otus. *ZooKeys* 1126: 1–54. doi:10.3897/zookeys.1126.87635

Miller B., Conway W., Reading R.P., Wemmer C., Wildt D., Kleiman D., Monfort S., Rabinowitz A., Armstrong B., Hutchins M. (2004) Evaluating the conservation mission of zoos, aquariums, botanical gardens, and natural history museums. *Conservation Biology* 18(1): 86–93. doi:10.1111/j.1523-1739.2004.00181.x

Newbold T., Hudson L.N., Hill S.L.L., Contu S., Lysenko I., Senior R.A. (2015) Global effects of land use on local terrestrial biodiversity. *Nature* 520(7545): 45–50. doi:10.1038/nature14324

Nijman V., Listina Sari S., Siriwat P., Sigaud M., Nekaris A.I. (2017) Records of four Critically Endangered songbirds in the markets of Java suggest domestic trade is a major impediment to their conservation. *BirdingASIA* 27: 20–25.

R Core Team (2021) *R: A Language and Environment for Statistical Computing.* Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/

Rech I., Ginal P., Rauhaus A., Ziegler T., Rödder D. (2023) Geckos in zoos: A global approach on distribution patterns of threatened geckos (Gekkota) in zoological institutions. *Journal for Nature Conservation* 75: 126467. doi:10.1016/j.jnc.2023.126467

Rosenberg K.V., Dokter A.M., Blancher P.J., Sauer J.R., Smith A.C., Smith P.A., Stanton J.C., Panjabi A., Helft L., Parr M., Marra P.P. (2019) Decline of the North American avifauna. *Science* 366(6461): 120–124. doi:10.1126/science.aaw1313

Slikas B., Jones I.B., Derrickson S.R., Fleischer R.C. (2000) Phylogenetic relationships of Micronesian white-eyes based on mitochondrial sequence data. *The Auk* 117(2): 355–365. doi:10.1093/auk/117.2.355

Slowikowski K. (2021) ggrepel: A*utomatically Position Non-Overlapping Text Labels with 'ggplot2'.* Version R package version 0.9.1. https://cran.R-project.org/package=ggrepel

Tietze D.T. (ed.). (2018) Bird Species. Cham, Switzerland: Springer Nature.

Warnes G.R., Bolker B., Lumley T. (2021) *gtools: Various R Programming Tools.* Version R package version 3.9.2. https://CRAN.R-project.org/package=gtools

Whelan C.J., Şekercioğlu Ç.H., Wenny D.G. (2015) Why birds matter: From economic ornithology to ecosystem services. *Journal of Ornithology* 156(S1): 227–238. doi:10.1007/s10336-015-1229-y

Wickham H. (2016) *ggplot2: Elegant Graphics for Data Analysis*. New York, New York: Springer-Verlag. https://ggplot2.tidyverse.org

Wickham H., François R., Henry L., Müller K. (2021) *dplyr: A Grammar of Data Manipulation.* Version R package version 1.0.7. https://cran.R-project.org/package=dplyr

Wickham H., Seidel D. (2020) *scales: Scale Functions for Visualization.* Version R package version 1.1.1. https://cran.R-project.org/package=scales

Winkler D.W., Billerman S.M., Lovette I.J. (2015) *Bird Families of the World. An Invitation to the Spectacular Diversity of Birds.* Barcelona, Spain: Lynx.

World Wide Fund For Nature (WWF) (2020) L*iving Planet Report – 2020: Bending the Curve of Biodiversity Loss.* Gland, Switzerland: WWF.

ZIMS (2021) *Species360 - Zoological Information Management Software (ZIMS)*. https://zims.species360.org