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RESEARCH ARTICLE

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Review of threatened Malagasy freshwater fishes in zoos and aquaria: The necessity of an ex situ conservation network—A call for action

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Abstract

Madagascar's biota is characterized by an extraordinary species richness, with a high degree of endemism. The island's freshwater habitats harbor numerous micro-endemic species, restricted to particular regions and thus particularly at risk of extinction, due to deforestation, overfishing, and introduction of exotic species. The present study investigates for which threatened Malagasy freshwater fish species ex situ populations have already been established, as a baseline to prioritize actions to develop an effective ex situ conservation breeding network. Populations in zoos and aquaria were primarily determined using the Zoological Information System. Of 173 fish species recorded from Malagasy freshwater habitats, 123 exclusively inhabit freshwater; 79 of these are endemic to Madagascar, and 50 are classified as threatened. Our survey found 21 Malagasy freshwater fish species kept in zoos worldwide, of which 19 are endemic and threatened (22 if counting species kept by private breeders). Nine of the 19 Malagasy freshwater fish species kept in zoos have successfully reproduced within the 12 months preceding our survey. The ex situ conservation activities for threatened Malagasy freshwater fishes thus have not improved significantly since the strong start in the early 2000s. More than half of the 50 threatened endemic Malagasy freshwater fish species (viz. 31 species) are not kept ex situ, including 11 species ranked as Critically Endangered. Based on these findings we call for a better distribution of offspring among institutions, including private breeders in the framework of citizen conservation initiatives; a closer connection of ichthyological field research in Madagascar with conservation breeding efforts to set up ex situ populations—both in Madagascar and abroad—of species not yet kept in captivity; and the development of effective, integrated in situ and ex situ conservation strategies.

KEYWORDS
aquatic vertebrates, conservation breeding, Madagascar

1 | INTRODUCTION

Madagascar, the world's fourth largest island and situated in the Indian Ocean (Benstead et al., 2003), has probably been isolated from any other land masses for the last 88 million years (Ali & Huber, 2010; Ali & Vences, 2019), despite recurrent speculations about subaerial terrestrial causeways in the Cenozoic (Masters et al., 2020).

As a result of this isolation, Madagascar has a unique flora and fauna characterized by a high level of endemism. Nearly 90% of all animal and plant species found are endemic (Goodman & Benstead, 2003). Madagascar also offers a large variety of biomes characterized by distinct climatic conditions conducive to micro-endemism, viz. organisms whose populations are limited to a small habitat area only, e.g., a single lake, a tiny rock island or mountain, or a short river section (Ganzhorn et al., 2016; Wilmé et al., 2006). These micro-endemic species are particularly threatened by extinction because their habitats are being destroyed quickly, often before conservation measures can become effective (Passal, 2015). Based on the criteria of Myers et al. (2000), such as diversity of species, endemism, and loss in habitat, Madagascar has been recognized as a global hotspot for biodiversity conservation (Ganzhorn et al., 2008; Groombridge & Jenkins, 1998).

Human colonization of Madagascar has been hypothesized to be older than 10,000 years (Anderson et al., 2018). Other studies point at the presence of humans at the island from about 3500 years before present (Anderson et al., 2018), which is shortly before the island's biodiversity became substantially affected (e.g., Burney et al., 2003). As a consequence, the local vegetation has been lost in large parts of the central highland (Benstead et al., 2003; Ganzhorn et al., 2016; Harper et al., 2007). In total, Lowry et al. (1997) estimated a habitat loss of 90%. Human interventions have also negatively affected all freshwater habitats, mainly through the combination of overfishing, deforestation, and introduction of neozoans (exotic species). As a consequence, freshwater fishes can be considered as the most threatened vertebrates of Madagascar (Benstead et al., 2003; Taylor 1986).

Of the 143 fish species listed by Sparks and Stiassny (2003), all those that complete their entire life cycle in fresh water—over 65%—are endemic, and many of them also micro-endemic. Malagasy freshwater fishes are phylogenetically often splitting from relatively basal nodes in their respective clades in the actinopterygian tree (Benstead et al., 2003) and thus are evolutionary unique (Stiassny & de Pinna, 1994).

According to Benstead et al. (2003), 22% of Madagascar's freshwater fishes assessed at the time were Critically Endangered, 34% Endangered, 17% Vulnerable, 5% Near Threatened and 4% already Extinct, using criteria established by the International Union for Conservation of Nature and Natural Resources (IUCN, 2001). Habitat conservation measures are urgently required to prevent further extinctions, but for many species, ex situ captive breeding at this time represented the only reliable means to save them from extinction (Benstead et al., 2003; Loiselle, 2003). In this context, it was and is obvious that zoos, being important conservation centers with global network activities, have the potential to contribute by preserving viable populations of species threatened with extinction due to the increased loss of habitats in the wild (Conde, 2013; Wayre, 1969).

Eighteen years after the studies of Benstead et al. (2003) and Loiselle (2003), we aimed to assess which threatened Malagasy freshwater fish species ex situ populations have been built up, and to use this information to prioritize actions to develop an effective ex situ conservation breeding network supportive to in situ fish conservation measures (Conde, 2013). For this purpose, we surveyed holdings in zoos and aquaria, tabulating the number of species kept, the number of individuals per species, the number of institutions keeping a species, and those with breeding success over the last 12 months, from the Zoological Information Management System (ZIMS: Species360). These surveys were performed at a global scale but focusing on Europe as a regional example. The ZIMS data were supplemented with data from the database List of Zoo Animals (ZTL). In addition, a preliminary survey was initiated to include private holdings of threatened Malagasy freshwater fishes. Based on these findings we provide a call for action and have drafted a commentarial guide.

2 | MATERIALS AND METHODS

A list of Malagasy freshwater fish species was compiled based on the database FishBase (Froese & Pauly, 2019). Only scientifically named species were considered. Based on the World Register of Marine Species (WoRMs Editorial Board, 2020), 46 species were designated as not exclusively occurring in freshwater. They were marked in Table 1 (e.g., the sharks *Carcharhinus amboinensis*, *C. leucas*) but then excluded from further analyses.

Fish species were classified as "introduced" (i.e., not naturally occurring in Madagascar), "native" (naturally occurring in Madagascar but also elsewhere) and "endemic" (naturally occurring and only found in Madagascar). The status of introduced species was cross-checked with information from FAO Fisheries and Aquaculture Department (2017), and these species (see Table 1) were excluded from all further analyses. Additionally, the conservation status and population trend of each species according to IUCN (2020) was added. The distribution data were compared with Froese and Pauly (2019) and the range completed, if necessary. The endemic species were further sub-classified into occurring nationwide (endemic), only regionally but occurring in more than one site (e.g., more than one river section) (regionally endemic), or at one restricted site only (e.g., limited to one river section or basin) (micro-endemic).

In addition, information on the IUCN (2020) threat status was collected. The species categorized by IUCN (2020) as Vulnerable (VU), Endangered (EN) and Critically Endangered (CR), were considered as "threatened" in this analysis. Additional threat categories were Extinct (EX), Near Threatened (NT), Data Deficient (DD), Not Evaluated (NE) and Least Concern (LC).

To gain an overview of native Malagasy freshwater fish species globally held in zoos, the number of individuals kept, the number of

TABLE 1 Fish species reported from Malagasy freshwater habitats (n = 173), alphabetically sorted by family, including source, conservation status, population trend (IUCN, 2020), records in ZIMS and/or ZTL

Family Species	Source	IUCN status	Pop. trend	ZIMS	ZTL
Ambassidae					
Ambassis ambassis+	Nat	LC	?		
A. fontoynonti	End	DD	?		
A. gymnocephalus+	Nat	LC	?		
A. natalensis+	Nat	LC	?	x	
A. urotaenia	Nat	LC	—		
Anabantidae					
Microctenopoma ansorgii	Int	LC	?	x	
Anchariidae					
Ancharius fuscus	End	LC	?		
A. griseus	End	EN	?		
Gogo arcuatus	End	DD	?		
G. atratus	End	DD	?		
G. brevibarbis	End	DD	?		
G. ornatus	End	EN	?		
Anguillidae					
Anguilla bicolor	Nat	NT	?		
A. labiata	Nat	LC	?		
A. marmorata	Nat	LC	?	x	
A. mossambica	Nat	NT	?		
Aplocheilidae					
Pachypanchax arnoulti	End	VU	↓	x	x
P. omalonotus	End	EN	↓	x	x
P. patriciae	End	EN	?	x	
P. sakaramyi	End	EN	↓	x	x
P. sparksorum	End	EN	↓		
P. varatraza	End	EN	?		x
Apogonidae					
Fibramia lateralis+	Nat	LC	?		
Arapaimidae					
Heterotis niloticus	Int	LC	?	x	
Ariidae					
Arius africanus	Nat	DD	?		
A. festinus	End	CR	↓		
A. madagascariensis+	Nat	LC	?		
A. uncinatus	End	CR	↓		
Plicofollis dussumieri+	Nat	LC	—		
Atherinidae					
Teramulus kieneri	End	LC	?		
T. waterloti	End	EN	↓		
Bedotiidae					
Bedotia albomarginata	End	EN	?		
B. alveyi	End	NT	?		
B. geayi	End	EN	↓	x	x
B. leucopteron	End	EN	?		
B. longianalis	End	EN	—	x	
B. madagascariensis	End	EN	↓	x	x
B. marojejy	End	EN	↓	x	
B. masoala	End	VU	?		
B. tricolor	End	CR	?		
Rheocles alaotrensis	End	EN	↓		
R. derhami	End	CR	↓		
R. lateralis	End	CR	↓		
R. pellegrini	End	DD	?		
R. sikorae	End	DD	?		
R. vatosoa	End	EN	↓	x	x
R. wrightae	End	EN	↓		
Carcharhinidae					
Carcharhinus amboinensis+	Nat	DD	?		
C. leucas+	Nat	NT	?	x	
Centrarchidae					
Lepomis macrochirus	Int	LC	—	x	
Micropterus salmoides	Int	LC	—	x	
Channidae					
Chanos chanos+	Nat	LC	?	x	
Channa maculata	Int	LC	?		
C. striata	Int	LC	?	x	
Cichlidae					
Coptodon rendalli	Int	LC	?	x	
C. zillii	Int	LC	?		
Katria katria	End	EN	↓		
Oreochromis aureus	Int	LC	?	x	
O. macrochir	Int	VU	?	x	
O. mossambicus	Int	NT	?	x	
O. niloticus	Int	LC	?	x	

TABLE 1 (Continued)

Family Species	Source	IUCN status	Pop. trend	ZIMS	ZTL
Oreochromis spilurus	Int	LC	?		
Oxylapia polli	End	EN	?		
Paratilapia polleni	End	VU	↓	x	x
Paretroplus dambabe	End	CR	↓		
P. damii	End	VU	?	x	x
P. gymnopreopercularis	End	CR	↓		
P. kieneri	End	VU	?	x	x
P. lamenabe	End	EN	?		
P. loisellei	End	EN	?	x	
P. maculatus	End	CR	↓	x	x
P. maromandia	End	EN	↓		
P. menarambo	End	CR	?	x	x
P. nourissati	End	EN	↓		x
P. petiti	End	DD	?		
P. polyactis	End	LC	↓		
P. tsimoly	End	EN	↓		
Ptychochromis curvidens	End	DD	?		
P. ernestmagnusi	End	DD	?		
P. grandidieri	End	LC	?	x	x
P. inornatus	End	EN	↓		
P. insolitus	End	CR	↓	x	x
P. loisellei	End	EN	↓	x	
P. mainty	End	DD	?		
P. makira	End	DD	↓		
P. oligacanthus	End	EN	↓	x	
P. onilahy	End	EX	?		
Ptychochromoides betsileanus	End	CR	?		
P. itasy	End	CR	?		
P. vondrozo	End	EN	?		
Tilapia sparmanii	Int	LC	?	x	
Clupeidae					
Sauvagella madagascariensis	End	LC	?		
Sauvagella robusta	End	EN	?		
Cyprinidae					
Carassius auratus	Int	LC	?	x	
Cyprinus carpio	Int	VU	?	x	
Labeo rohita	Int	LC	?		

(Continues)

TABLE 1 (Continued)

Family Species	Source	IUCN status	Pop. trend	ZIMS	ZTL
Tanichthys albonubes	Int	DD	?	x	
Eleotridae					
Butis butis[+]	Nat	LC	—		
B. koilomatodon[+]	Nat	NE	?		
Eleotris acanthopoma	Nat	LC	—		
Eleotris fusca[+]	Nat	LC	—		
E. mauritiana	Nat	LC	?		
E. pellegrini	End	LC	?		
E. vomerodentata	Nat	DD	?		
Giuris margaritacea	Nat	LC	—		
Hypseleotris cyprinoides[+]	Nat	DD	?		
H. tohizonae	End	NE			
Ophiocara macrolepidota	End	NE			
Ophiocara porocephala[+]	Nat	LC	—		
Ratsirakia legendrei	End	DD	?		
Gerreidae					
Gerres filamentosus[+]	Nat	LC	?		
Gobiidae					
Acentrogobius nebulosus[+]	Nat	LC	?	x	
A. therezieni[+]	End	DD	?		
Awaous aeneofuscus	Nat	LC	?		
A. commersoni	Nat	NE			
A. macrorhynchus	Nat	LC	?		
Bathygobius fuscus	Nat	LC	—		
Croilia mossambica[+]	Nat	LC	?		
Glossogobius ankaranensis	End	LC	?		
G. callidus[+]	Nat	LC	—		
G. giuris[+]	Nat	LC	?		
Gobiodon rivulatus[+]	Nat	NE			
Gobius hypselosoma	End	LC	?		
Mugilogobius mertoni[+]	Nat	LC	?		
Redigobius balteatus[+]	Nat	LC	?		
Redigobius bikolanus[+]	Nat	LC	—		
Sicyopterus fasciatus	Nat	DD	?		
S. franouxi	End	LC	?		
S. lagocephalus[+]	Nat	LC	?		
S. punctissimus	End	DD	?		
Sicyopus lord[+]	End	NE			

(Continues)

TABLE 1 (Continued)

Family Species	Source	IUCN status	Pop. trend	ZIMS	ZTL
Stenogobius genivittatus+	Nat	LC	?		
S. polyzona	Nat	LC	?		
Taenioides gracilis	Nat	LC	?		
Haemulidae					
Plectorhinchus gibbosus+	Nat	LC	—		
Kraemeriidae					
Gobitrichinotus arnoulti	End	LC	?		
Kuhliidae					
Kuhlia caudavittata+	Nat	NE			
K. mugil+	Nat	LC	?	x	
K. rupestris+	Nat	LC	—		
K. sauvagii	End	VU	—		
Megalopidae					
Megalops cyprinoides+	Nat	DD	?	x	
Milyeringidae					
Typhleotris madagascariensis	End	EN	?		
T. mararybe	End	CR	—		
T. pauliani	End	CR	?		
Mugilidae					
Agonostomus catalai+	Nat	DD	?		
A. telfairii	Nat	LC	?		
Mugil cephalus+	Nat	LC	—	x	
Planiliza alata+	Nat	LC	?		
P. macrolepis+	Nat	LC	—		
P. melinopterus+	Nat	LC	?		
Opichthidae					
Pisodonophis boro+	Nat	LC	?		
P. cancrivorus+	Nat	NE			
Osphronemidae					
Macropodus opercularis	Int	LC	↓	x	
Osphronemus goramy	Int	LC	—	x	
Poeciliidae					
Gambusia affinis	Int	LC	—	x	
G. holbrooki	Int	LC	—	x	
Pantanodon madagascariensis	End	EX	?		
Poecilia reticulata	Int	NE		x	
Xiphophorus hellerii	Int	LC	—	x	
Xiphophorus maculatus	Int	DD	?	x	
Pristidae					
Pristis microdon+	Nat	NE			
Pristigasteridae					
Pellona ditchela+	Nat	LC	?		
Salmonidae					
Oncorhynchus mykiss	Int	NE		x	
Scatophagidae					
Scatophagus tetracanthus+	Nat	LC	—		
Sillaginidae					
Sillago sihama+	Nat	LC	—	x	
Sparidae					
Acanthophagrus berda+	Nat	LC	?		
Syngnathidae					
Hippichthys cyanospilos+	Nat	NE			
Microphis brachyurus+	Nat	LC	?	x	
M. fluviatilis+	Nat	DD	?		
M. leiaspis+	Nat	LC	?		
M. millepunctatus+	Nat	NE			
Terapontidae					
Mesopristes elongatus	End	DD	?		
Terapon jarbua+	Nat	LC	?	x	

Note: Nat = native (nonendemic); End = endemic; Int = introduced; + = freshwater, brackish water and marine; ↓ = decreasing; — = stable.
Abbreviation: ZIMS, Zoological Information System.

keeping institutions, and successful reproduction within the last 12 months were analyzed based on information collected from ZIMS (https://zims.species360.org) database in spring 2020. The ZIMS list may miss some captive populations or breeding records, as some data may be obsolete or have not (yet) been entered in the database, and some zoos do not use ZIMS. To increase the coverage of our data set, we additionally cross-checked the ZIMS data with species holdings for further institutions in Germany and Europe recovered from the website "Zootierliste" (ZTL, List of Zoo Animals: https://zootierliste.de/) which includes holdings of additional institutions as well as some private zoos, rescue stations and other facilities (Graf et al., 2019). ZTL data were only analysed in our overall summary of species present in holdings as for most ZTL data the last entries date back to 4 years ago and thus are of limited relevance when quantifying current animal stocks.

For the analysis, all countries that geographically belong to the European continent were considered as "Europe". Moreover, as over 20% of Russia's land surface is located on the European continent, figures of Russian zoos were included in the ZIMS analyses as well.

To collect preliminary information about private fish holdings of Malagasy freshwater fishes, a questionnaire was developed and sent in June 2020 both to the Deutsche Cichliden-Gesellschaft e.V. (German Cichlid Society) and to the administrator of the Facebook group "Madagascar Endangered Fishes."

3 | RESULTS

3.1 | Species diversity and threat evaluation

A total of 173 fish species representing 35 different families are currently reported to occur in Malagasy freshwater habitats (Froese & Pauly, 2019); 123 of them are restricted to pure freshwater (see Table 1), in the following referred to as Malagasy freshwater fish species. Cichlids, with 37 species, are the most diverse Malagasy freshwater fish family, followed by bedotiids (16 species). Of the 123 species, 26 are introduced (21%), and 97 are native (79%). Of the native species, 79 are endemic (64%; Figure 1). All species of the families Bedotiidae (16), Anchariidae (6) and Aplocheilidae (6) are endemic to Madagascar. Among all cichlids occurring in Madagascar, 29 species (78%) are endemic, the other eight species (22%) are introduced.

According to IUCN (2020), more than half of Madagascar's native freshwater fish species are threatened (50 of 97 species). Fifty of the 79 endemic Malagasy freshwater fish species (63%) are threatened (Figures 1 and 2; Table 2). Of the 79 endemic freshwater fish species, 16 are micro-endemic (Table 3), with 13 of them being threatened; and four are regionally endemic (Table 4), all of them being threatened. The 29 endemic Malagasy freshwater fish species which are not listed as threatened correspond to the categories Data Deficient or Not Evaluated. Two species, *Pantanodon madagascariensis* and *Ptychochromis onilahy* are considered as Extinct. Most of the threatened species (60%) are listed as Endangered. The population trend is declining in 37% of the endemic freshwater fish species. For 50 endemic Malagasy freshwater fish species (63%), the extent of population decline is unknown. Only for one of the species listed as Data Deficient or Not Evaluated, a population trend was indicated (*Ptychochromis makira*, with population declining).

4 | ZIMS ANALYSIS

4.1 | Malagasy freshwater fish species globally held in zoos

According to ZIMS 20 native Malagasy freshwater fish species are globally held in zoos. In total, they account for 4267 individuals (Figure 3). The vast majority of these (19 of 20 species; 4262 individuals) are Madagascar-endemics and about 90% of the species (18 species; 2972 individuals) are threatened. The native species *Anguilla marmorata* (represented by a population of five captive individuals) and the endemic species *Ptychochromis grandidieri* (1290 captive individuals) are not threatened and listed as Least Concern by the IUCN (2020) (see Table 1).

4.2 | Malagasy freshwater fish species held in zoos by continents

The highest numbers of Malagasy freshwater fish species are held in North American zoos (16 species) and European zoos (15 species), with very few records from Asian and South American zoos.

The 16 species held in North American zoos are represented by three families: Bedotiidae (four species), Cichlidae (nine species) and Aplocheilidae (three species) (see Figure 4). All of these species are endemic to Madagascar, with *Bedotia geayi* being the most common species (with 201 individuals). However, many if not all of these records may in fact represent *Bedotia madagascariensis*

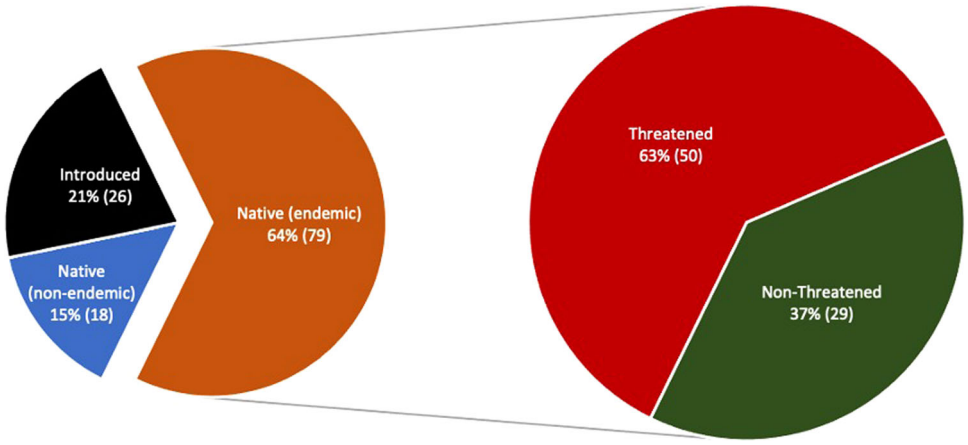

FIGURE 1 Percentage of introduced, native and endemic Malagasy freshwater fish species ($n = 123$) including percentage of threatened endemic species, absolute species numbers in parentheses

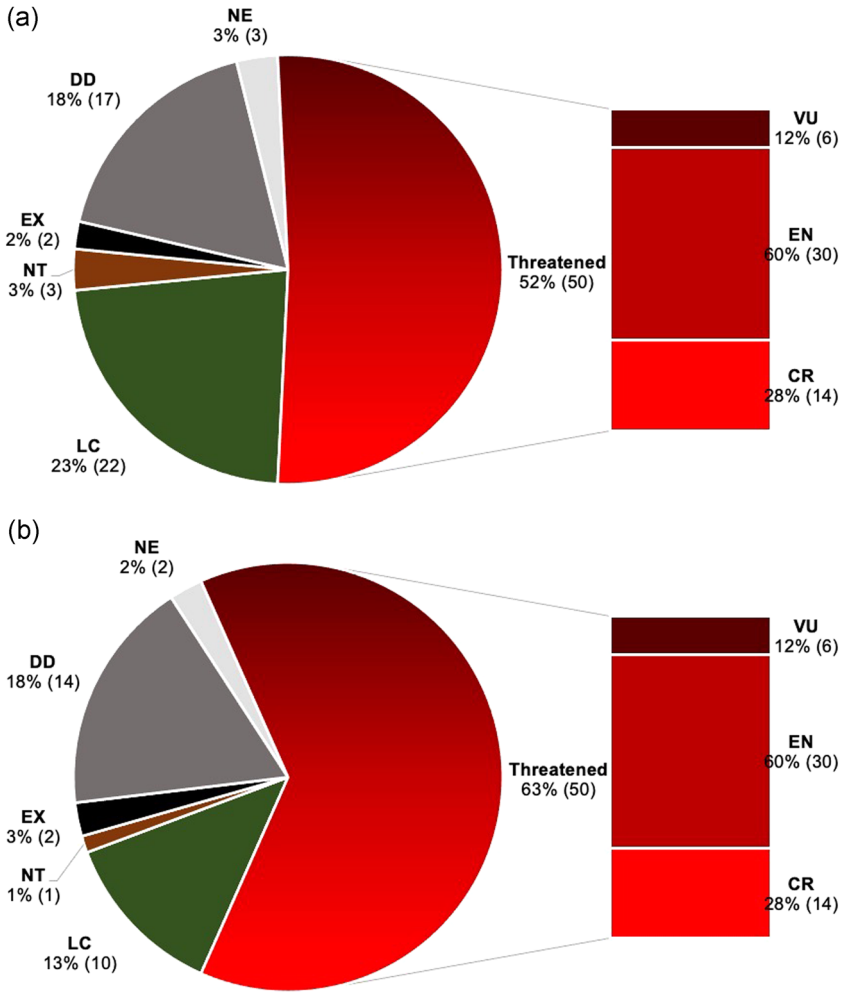

FIGURE 2 Threat status of Malagasy freshwater fish species (in %) after IUCN (2020): (a) all species (n = 97); (b) endemic species (n = 79); absolute species numbers in parentheses. CR, critically endangered; DD, data deficient; EN, endangered; EX, extinct; LC, least concern; NE, not evaluated; NT, near threatened; VU, vulnerable

IUCN category	Native species: 97	Endemic species: 79 (29)	Micro-endemic species: 16 (10)
Threatened			
Critically Endangered (CR)	14	14 (8)	7 (6)
Endangered (EN)	30	30 (17)	5 (3)
Vulnerable (VU)	6	6 (2)	1 (?)
Other categories			
Extinct (EX)	2	2 (–)	0 (–)
Near Threatened (NT)	3	1 (0)	0 (–)
Least Concern (LC)	22	9 (1)	0 (–)
Data Deficient (DD)	17	15 (1)	3 (1)
Not Evaluated (NE)	3	2 (?)	0 (–)

TABLE 2 Threat evaluation of native and endemic Malagasy freshwater fish species, respectively; in brackets endemic species with declining population trend (after IUCN, 2020)

(see Section 5.3). The *B. geayi* records are followed by *Rheocles vatosoa* (with 81 individuals). *Paretroplus loisellei* and *Ptychochromis oligacanthus* are the rarest species held in North American zoos.

The 15 species held in European zoos are likewise represented by the same three families: Bedotiidae (four species), Cichlidae (eight species) and Aplocheilidae (three species) (see Figure 6). *Ptychochromis grandidieri* is the most common species in Europe, with in total 1283 held individuals, followed by *Pachypanchax sakaramyi* with 510 individuals, and *Paratilapia polleni* (345 individuals). *Bedotia longianalis* represents the rarest species held in a European zoo.

TABLE 3 Micro-endemic Malagasy freshwater fish species, alphabetically sorted by family, including IUCN status and distribution

Family	Species	IUCN status	Distribution	Authors
Anchariidae	*Gogo atratus*	DD	Mananara du Nord River (lower course)	Ng et al. (2008)
	G. brevibarbis	DD	Mananjary River (upper and middle courses)	Ng and Sparks (2005)
Ariidae	*Arius uncinatus*	CR	Lake Andrapongy (Ankofia River drainage)	Ng and Sparks (2003)
Bedotiidae	*Bedotia geayi*	EN	Mananjary River basin	Loiselle and Rodriguez (2007)
	B. leucopteron	EN	Rianila basin	Loiselle and Rodriguez (2007)
	B. masoala	VU	short sections of Ankananava River	Sparks (2016)
	Rheocles derhami	CR	Amboaboa River	Sparks (2016a)
	R. lateralis	CR	upper course of Mandolotra River	Reinthal and Stiassny (1997)
	R. vatosoa	EN	upper course of the Lokoho basin	Stiassny et al. (2002)
Cichlidae	*Oxylapia polli*	EN	Marolambo rapids of Nosivolo River	Ravelomanana (2016)
	Paretroplus dambabe	CR	Lake Kinkony	Sparks (2008)
	P. gymnopreopercularis	CR	Amboaboa River	IUCN (2020)
	P. menarambo	CR	Lake Tseny	IUCN (2020)
	Ptychochromis insolitus	CR	Amboaboa tributary to Mangarahara River	Stiassny and Sparks (2006)
	P. loisellei	EN	Mahanara basin	Stiassny and Sparks (2006)
	P. makira	DD	sections of Antainambalana River	Sparks and Stiassny (2010)

TABLE 4 Regionally endemic Malagasy freshwater fish species, alphabetically sorted by family, including the distribution; in view of habitat loss, e.g., due to deforestation, there is a risk that *Paretroplus nourissati* will soon be classified as micro-endemic as well

Family	Species	IUCN status	Distribution	Author
Cichlidae	*Paretroplus nourissati*	EN	Sofia River basin	Sparks (2008)
Milyeringidae	*Typhleotris madagascariensis*	EN	Cave systems in south-western Madagascar	Sparks and Chakrabarty (2012), Vences et al. (2018)
	T. mararybe	CR		
	T. pauliani	CR		

In Asia, the native, nonthreatened *Anguilla marmorata* (Anguillidae) is the only species held. It is not probable that the five individuals kept originate from Malagasy populations.

Also, in South America only one species is held, *Bedotia geayi* (Bedotiidae), with a single individual reported.

4.3 | Malagasy freshwater fish species held in zoos in Europe

A total of 14 of the 15 Malagasy freshwater fish species held within European zoos are listed as threatened by IUCN (2020). This represents 2319 individuals, three times the number of threatened individuals held outside of Europe (653). However, there is a slightly greater number of different species (16) held outside Europe than in Europe (14).

Within Europe, most of the Malagasy freshwater fish species are held in Germany (see Figure 5). 11 of the 12 species kept in Germany are listed as threatened by IUCN (2020). A total of 744 out of 749 (99%) of the individuals kept in Germany belong to threatened species. Most threatened Malagasy freshwater fish species ($n = 7$) are held at the Cologne Zoo, followed by Aquazoo in Düsseldorf ($n = 4$).

In United Kingdom, 10 threatened Malagasy freshwater fish species are held in zoos, followed by Czech Republic (seven threatened species) and the Netherlands and Switzerland (each with five threatened species).

The family Bedotiidae is represented by five species in European zoos. *Bedotia geayi* is kept in seven European countries (see Figure 6); however, these may in fact represent *B. madagascariensis*, which explicitly is kept in five European countries. *Rheocles vatosoa* is kept only in Germany and in United Kingdom with few individuals. *Bedotia longianalis* is only kept in Czech Republic, with one individual (see Figure 6).

The family Cichlidae is represented by eight species in European zoos. *Paratilapia polleni* and *Paretroplus menarambo* are kept in most countries on the European continent ($n = 7$), followed by *Paretroplus*

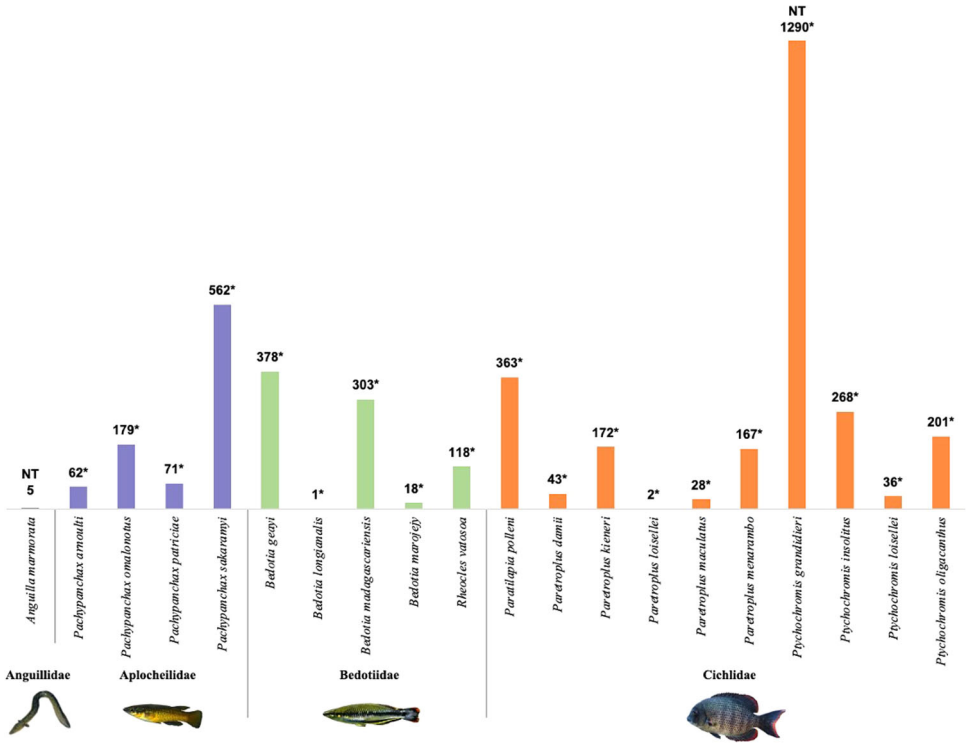

FIGURE 3 Number of Malagasy freshwater fish individuals (n = 4267) globally held in zoos (bars coloured according to family; * = endemic species; NT = nonthreatened species), after ZIMS. ZIMS, Zoological Information System

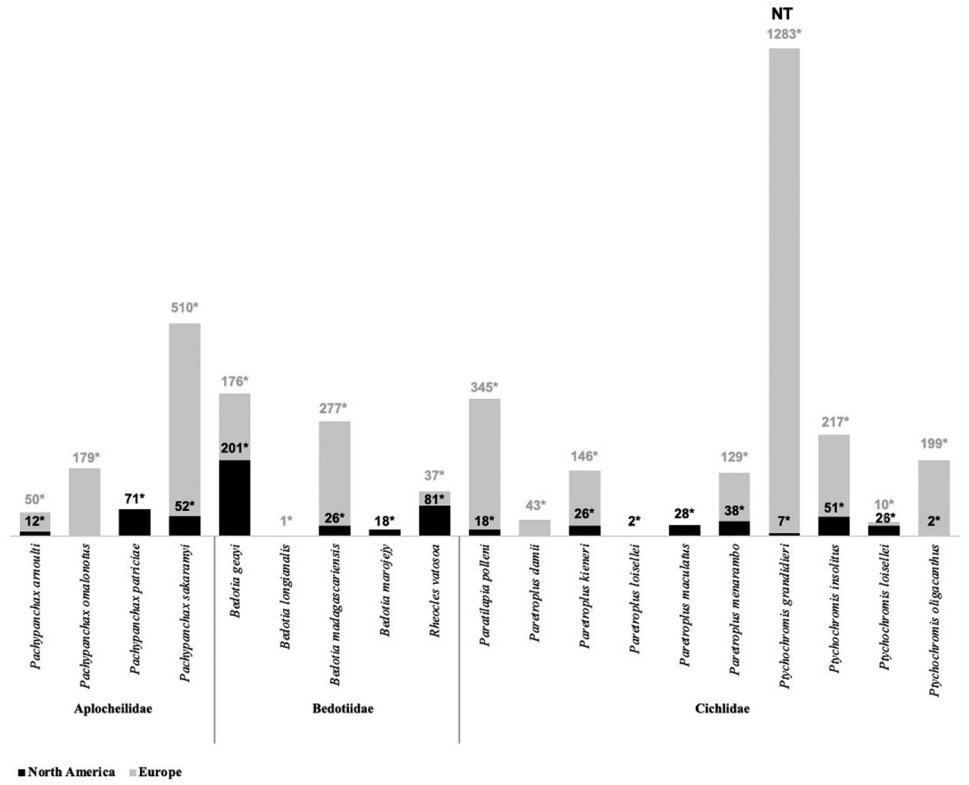

FIGURE 4 Number of Malagasy freshwater fish individuals held in North American (n = 659) and European (n = 3602) zoos (NT = nonthreatened species; * = endemic species)

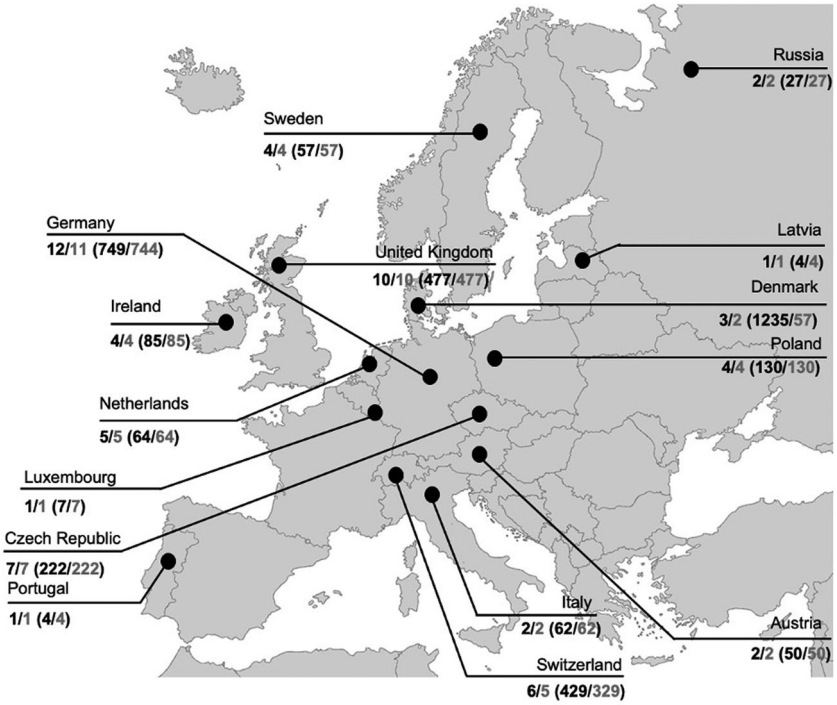

FIGURE 5 Total number of Malagasy freshwater fish species (and individuals in parentheses) kept in zoos in the European region (n = 3602); threatened Malagasy freshwater fish species and individuals in grey, respectively

kieneri (kept in six countries). *Ptychochromis insolitus* is held in four countries, with the largest group being held in Germany. The endemic but nonthreatened *Ptychochromis grandidieri* is held in three countries, with highest individual numbers (1178) in Denmark (in a single institution). *Paretroplus damii* is held in two countries, with 35 individuals in United Kingdom and eight individuals in the Netherlands. *Ptychochromis loisellei* was only kept at the Cologne Zoo in Germany a few years ago until offspring was distributed from there to other zoos (Ziegler et al., 2020) (see Figure 6).

The family Aplocheilidae is represented by three species in European zoos. *Pachypanchax sakaramyi* is kept in eight countries, followed by *Pachypanchax omalonotus* (kept in six countries). *Pachypanchax arnoulti* is kept only in two institutions, one in Germany (Aquazoo Düsseldorf, 30 individuals) and one in United Kingdom (ZSL London Zoo, 20 individuals) (see Figure 6).

4.4 | Reproduction success

According to ZIMS, a total of ten out of the 20 globally zoo-kept Malagasy freshwater fish species successfully reproduced within the 12 months preceding our survey (see Table 5). All of the 10 species, distributed among three families, were both endemic and threatened. In North America, six species successfully reproduced (*Pachypanchx arnoulti*, *Pachypanchax sakaramyi*, *Bedotia geayi*, *B. marojejy*, *Paretroplus kieneri*, *P. loisellei*). In Europe, nine species successfully reproduced (*Bedotia geayi*, *B. madagascariensis*, *Rheocles vatosoa*, *Pachypanchax arnoulti*, *Pachypanchax omalonotus*, *Pachypanchax sakaramyi*, *Paretroplus kieneri*, *Ptychochromis insolitus*, and *Ptychochromis loisellei*), with *Ptychochromis insolitus* and *P. loisellei* having bred for the first time in zoos in Europe (Ziegler et al., 2020). However, de Rham and Nourissat (2002) reported about their breeding of *Pt.* "de Mandristsara" (sic), which might apply (due to the region of Mandritsara) to another breeding success of *P. insolitus*, this time in a private facility.

5 | ZTL ANALYSIS

According to ZTL a total of 15 Malagasy freshwater fish species are held in zoos in Europe. All 15 species are endemic to Madagascar. A total of 13 of them are listed both in ZIMS and ZTL. Two species, *Pachypanchax varatraza* and *Paretroplus nourissati*, are not listed in ZIMS. The former species, *P. varatraza*, is kept at Aquazoo Düsseldorf, Germany only and the latter species, *P. nourissati*, according to ZTL, at ZSL Whipsnade Zoo in United Kingdom; however, the species is only depicted on a display panel at ZSL Whipsnade Zoo, but not really present, thus in fact not held (C. Fusari, pers. comm.).

In total another 11 breeding groups for two members (*Pachypanchax omalonotus*, *P. sakaramyi*) of the family Aplocheilidae appear in ZTL (in Austria [1], Czech Republic [1], Germany [5], United Kingdom [2] and Switzerland [1]), which are not recorded in ZIMS.

For two species (*Bedotia geayi*, *B. madagascariensis*) of the family Bedotiidae another 12 husbandries appear in ZTL (in Czech Republic [1], Denmark [1], France [1], Germany [4], United Kingdom [1], Hungary [1], Luxemburg [1], Poland [1] and Spain [1]), which are not recorded in ZIMS.

And for seven species (*Paratilapia polleni*, *Paretroplus damii*, *P. kieneri*, *P. maculatus*, *P. menarambo*, *Ptychochromis grandidieri* and *P. insolitus*) of the family Cichlidae another 29 husbandries appear in ZTL (in Austria [1], Germany [2], United Kingdom [5], France [2], Netherlands [1], Poland [1], Russia [4], Spain [1]), which are not recorded in ZIMS (*Paretroplus nourissati* was excluded here for the reasons given above).

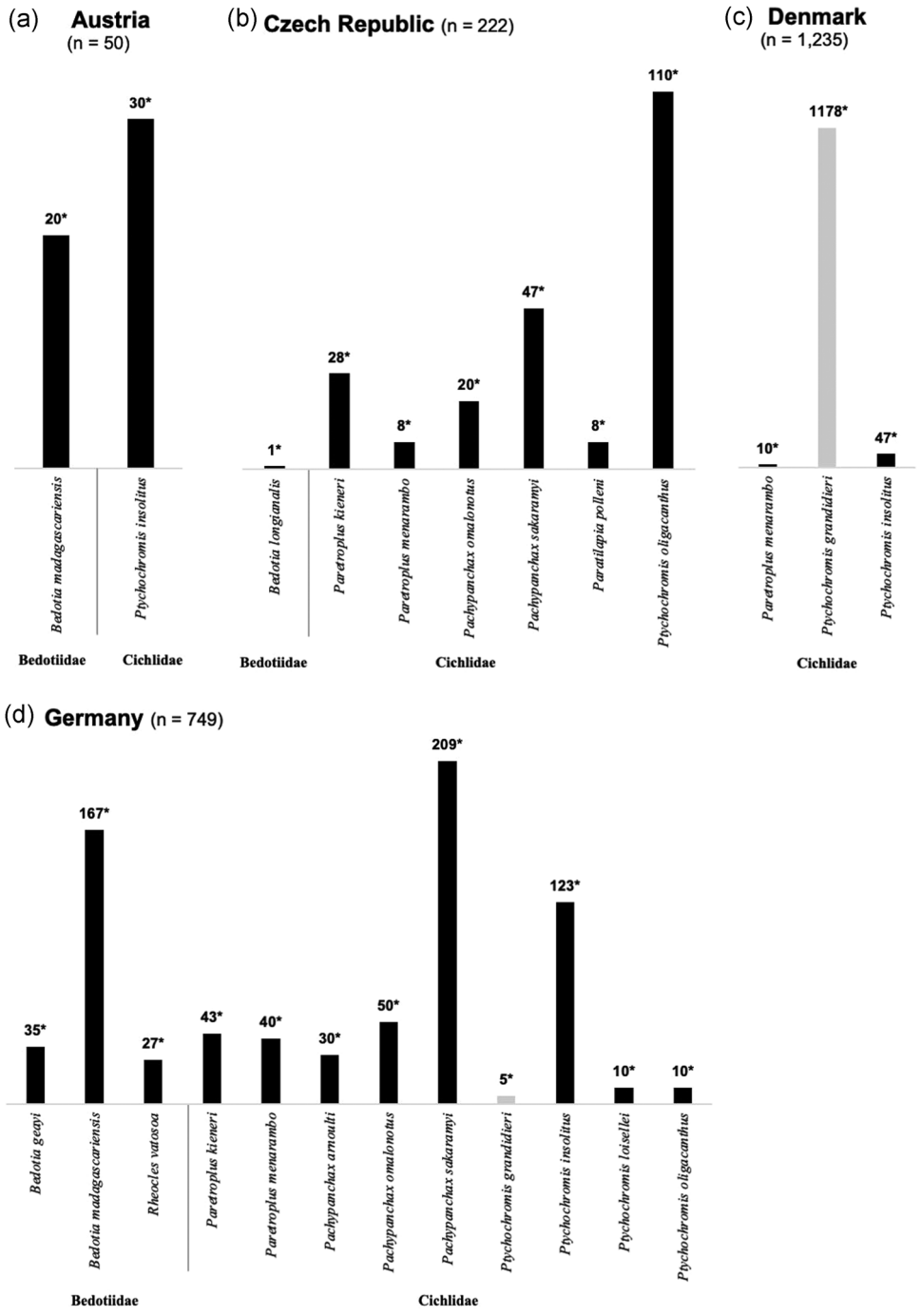

FIGURE 6 Number of Malagasy freshwater fishes held in European zoos per country; threatened Malagasy freshwater fish species in black

5.1 | Threatened endemic Malagasy freshwater fish species that are not yet held in captivity

In total 31 endemic, threatened (IUCN, 2020) Malagasy freshwater fish species are not yet held in zoos globally according to ZIMS (Table 6).

5.2 | Threatened Malagasy freshwater fish species kept by hobbyists

Two private owners from the Facebook group "Madagascar Endangered Fishes" have responded to our survey released in June 2020. Accordingly, at least 15 endemic Malagasy freshwater fish

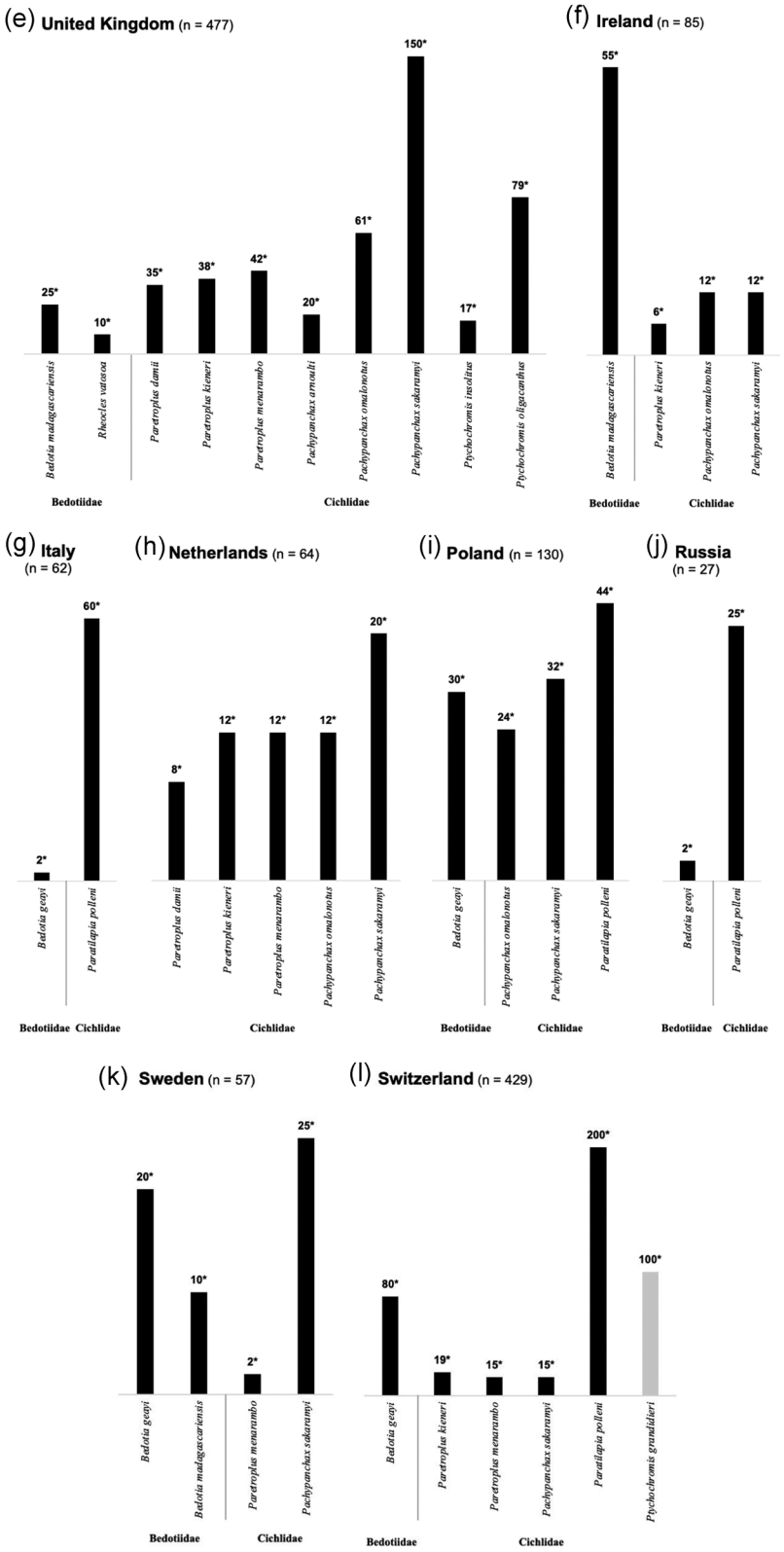

FIGURE 6 Continued

TABLE 5 Total number of Malagasy freshwater fishes that successfully reproduced in zoos during the 12 months preceding our survey (ZIMS)

Family *Species*	Institution	Offspring	Total
Aplocheilidae			
Pachypanchax arnoulti	ZSL London Zoo	13	16
	Toronto Zoo	3	
P. omalonotus	Wroclaw Zoo	20	20
P. sakaramyi	ZSL London Zoo	16	63
	Leipzig Zoo	20	
	Ostrava Zoo	9	
	New York Aquarium (Brooklyn)	18	
Bedotiidae			
Bedotia geayi	Wroclaw Zoo	15	73
	New York Aquarium (Brooklyn)	8	
	Cleveland Metroparks Zoo	50	
B. madagascariensis	Zoological Garden Bernburg	13	129
	Fota Wildlife Park (Ireland)	50	
	Cologne Zoo	66	
B. marojejy	Toronto Zoo	6	6
Rheocles vatosoa	ZSL London Zoo	72	93
	Toronto Zoo	21	
Cichlidae			
Paretroplus kieneri	Leipzig Zoo	25	30
	Bronx Zoo	5	
Ptychochromis insolitus	Cologne Zoo	158	158
P. loisellei	Cologne Zoo	50	135
	Toronto Zoo	85	

species are kept by private breeders (Table 7). Of them, *Ptychochromis grandidieri* is Not Threatened (LC), and *P. mainty* Data Deficient (DD). Three of the privately kept species are not yet represented in zoos according to ZIMS and ZTL: the aplocheilid *Pachypanchax sparksorum* and the cichlid species *Paretroplus dambabe* and *P. nourissati*.

5.3 | Discussion and recommendations

Of the 173 freshwater fish species from Madagascar, 123 are exclusively found in pure freshwater. Of these, 97 species are native, and 79 are endemic to Madagascar (see Table 1). In the past two

TABLE 6 Threatened endemic Malagasy freshwater fish species that are not yet held in captivity (ZIMS), including ZTL information (n = 31); sorted alphabetically by family including conservation status (IUCN, 2020) and information on micro-endemism (xx)/regional endemism (x)

Family *Species*	Status	Endemism
Anchariidae		
Ancharius griseus	EN	
Gogo ornatus	EN	
Aplocheilidae		
Pachypanchax sparksorum	EN	
Ariidae		
Arius festinus	CR	
Arius uncinatus	CR	xx
Atherinidae		
Teramulus waterloti	EN	
Bedotiidae		
Bedotia albomarginata	EN	
B. leucopteron	EN	
B. masoala	VU	xx
B. tricolor	CR	
Rheocles alaotrensis	EN	
R. derhami	CR	xx
R. lateralis	CR	
R. wrightae	EN	
Cichlidae		
Katria katria	EN	xx
Oxylapia polli	EN	xx
Paretroplus. dambabe	CR	
P. gymnopreopercularis	CR	
P. lamenabe	EN	
P. maromandia	EN	
P. nourissati	EN	x
P. tsimoly	EN	
Ptychochromis inornatus	EN	
Ptychochromoides betsileanus	CR	
P. itasy	CR	xx
P. vondrozo	EN	
Clupeidae		
Sauvagella robusta	EN	
Kuhliidae		
Kuhlia sauvagii	VU	

TABLE 6 (Continued)

Family *Species*	Status	Endemism
Milyeringidae		
Typhleotris madagascariensis	EN	x
T. mararybe	CR	x
T. pauliani	CR	x

Abbreviations: CR, critically endangered; EN, endangered; VU, vulnerable.

TABLE 7 Malagasy freshwater fish species kept by hobbyists, alphabetically sorted by family, including number of adults, juveniles, generations, and conservation status (IUCN, 2020); in brackets individual numbers which could not be allocated either to adults or juvenile stages

Family *Species*	Adults	Juveniles	Generations	Status
Keeper 1				
Aplocheilidae				
Pachypanchax omalonotus	100	–	3.–4.	EN
P. sakaramyi	50	–	3.–4.	EN
P. sparksorum	100	–	3.–4.	EN
P. varatraza	8	–	1.	EN
Cichlidae				
Paretroplus dambabe	20	800	3.–4.	CR
Paretroplus damii	6	30	1.	VU
Paretroplus kieneri	20	–	3.–4.	VU
Paretroplus maculatus	8	200	3.–4.	CR
Paretroplus menarambo	30	–	3.–4.	CR
Paretroplus nourissati	20	200	3.–4.	EN
Ptychochromis grandidieri	40	–	3.–4.	LC
Ptychochromis mainty	20	500	2.	DD
Ptychochromis oligacanthus	20	500	3.–4.	EN
Keeper 2				
Cichlidae				
Paratilapia polleni	(6)	–	–	VU
Paretroplus maculatus	(2)	–	–	CR
Paretroplus dambabe	(2)	–	–	CR

Abbreviations: CR, critically endangered; DD, data deficient; EN, endangered; VU, vulnerable.

decades, more than 20 freshwater fish species have been scientifically named from Madagascar (see overview in Ziegler et al., 2020), which on average is at least one new species named each year. It can be assumed that even in the well-studied groups (cichlids, aplocheilids, bedotiids) further species will be discovered in the future, in particular micro-endemic taxa prone to extinction. Furthermore, the taxonomy of several rather species-rich families such as the Eleotridae and Gobiidae have not been thoroughly revised in Madagascar using integrative approaches, i.e., including molecular data sets, and it is likely that numerous unnamed species exist in these groups.

Besides the need for further field research in Madagascar in concert with intensified taxonomic revisions, the conservation status of many taxa also needs re-evaluation. Such re-assessment is needed for numerous Malagasy freshwater fish species whose threat situation has worsened locally since the last evaluation (Ziegler et al., 2020). For a number of species, assessments are so far completely lacking, such as for the micro-endemic anchariids *Gogo arcuatus* and *Gogo brevibarbis*. Also the cichlid *Ptychochromis makira* is classified DD due to the lack of a comprehensive survey. For 17 of the 79 known endemic Malagasy freshwater fish species, an assessment has so far not been possible due to insufficient data (DD) or lack of research (NE). With new assessments, the percentage of threatened endemic Malagasy freshwater fish species (63%) will certainly increase substantially. First recommendations were made by Ziegler et al. (2020), who suggested to upgrade *Gogo atratus* and *Ptychochromis ernstmagnusi* from DD to VU, and *Pachypanchax sakaramyi* from EN to CR. Even the number of species classified as Extinct by the IUCN (2020) (*Ptychochromis onilahy* and *Pantanodon madagascariensis*) could be underestimated (Máiz-Tomé et al. 2018). There might also be a few taxa to be downranked in threat status, such as *Bedotia leucopteron*, *B. madagascariensis*, *Pachypanchax patriciae*, *Ptychochromis oligacanthus*, and *Sauvagella robusta* (Ziegler et al., 2020).

According to our analysis of ZIMS data, 20 Malagasy freshwater fish species are kept in zoos worldwide, with 18 of them being endemic and threatened. By adding information from the Zootierliste database we could add the Endangered *Pachypanchax varatraza* (in Aquazoo Düsseldorf) which was not included in the ZIMS data, but which since recently also is held at the Cologne Zoo. This number of 19 endemic, threatened Malagasy freshwater fish species held amounts for less than one fourth only of the 79 endemic Malagasy freshwater fish currently recognized. Our assessment is probably not complete, however, given that ZIMS is used by around 1100 institutions worldwide (Species360, 2020), we are convinced the numbers presented here are quite representative of the actual situation. Hence, it is likely that more than half of the 50 threatened endemic Malagasy freshwater fish species (viz. 31 species) have no ex situ conservation component (see Table 6).

The paramount importance of ex situ conservation for Madagascar's freshwater fishes has been stressed by Benstead et al., (2003). Given that the combination of deforestation, overfishing, and exotic species introduction has affected most of Madagascar's freshwater habitats, captive breeding represents the only guaranteed means of saving a large proportion of Madagascar's endemic fishes from extinction—although persistence within original habitat continues being the optimal conservation strategy (Benstead et al.,

2003). Eighteen years ago, captive breeding efforts undertaken by public aquariums, zoos, and individuals in North America and Europe had resulted in the establishment of managed populations of 32 Malagasy fish species (Benstead et al., 2003).

However, with currently 19 threatened endemic Malagasy freshwater fishes held in zoos according to our analysis, the situation has not much improved since the strong beginning in the early 2000s. If we add the species confirmed through our survey held by private keepers (*Pachypanchax sparksorum*, *Paretroplus dambabe*, *P. nourissati*), there is evidence for a total of 22 threatened endemic Malagasy freshwater fishes currently held ex situ—most of them in Europe and the USA, and some of them at single or few institutions only. In total, eleven endemic species are classified as Critically Endangered, thus facing an extremely high risk of extinction in the wild, but which are not yet kept ex situ (Table 8). To obtain a stable conservation breeding network, we strongly recommend increased efforts to better distribute species among institutions, to prevent the loss of a given species due to unforeseen local events such as disease outbreak, accidents, natural disasters or technical failures (see also Jacken et al., 2020; Wahle et al., 2021).

A first initiative to move in this direction was the kind provision in 2019 of *Ptychochromis insolitus*, *P. loisellei* and *Rheocles vatosoa* offspring from Toronto Zoo in Canada to Cologne Zoo in Germany to enable the keeping or/and the breeding of these species in Europe. Of these species, *P. loiselli* was previously not present in any European zoo, and *P. insolitus* had previously been only kept in London Zoo in the United Kingdom (from 2002 to 2014) and for some time in the past in Berlin Zoo in Germany, without reproduction. Since the transfer, several hundreds of fry of the two *Ptychochromis* species have already been produced in Cologne Zoo, and more than 300 offspring of both species have been transferred to more than ten zoos in Germany and Europe, with hundreds of further juveniles available for further distribution (Ziegler et al., 2020). *Rheocles vatosoa* also reproduced meanwhile at the Cologne Zoo.

We recommend to expand the recently seeded conservation breeding network for these cichlids (not yet reflected in the ZIMS data summarized herein) to further species. For instance, our analysis identified several potential transfer opportunities within Europe (Figures 5 and 6), e.g., of *Pachypanchax arnoulti* that is kept in only two European zoos and has reproduced lately at ZSL London Zoo only (see Table 5), or of *Rheocles vatosoa* which equally is kept in two zoos only and has reproduced both at Cologne Zoo and ZSL London Zoo. In other cases, where existing captive stocks are very small and without reproduction recently, besides exchanges among institutions also restocking from limited new field collections are worth considering, in particular for taxa not yet represented in ex situ breeding programs.

To maintain the genetic diversity of breeding stocks, we recommend establishing studbooks and monitoring programs for threatened taxa, in which exchange of genetic lines is coordinated. In case of unknown origin or to test the purity of breeding, genetic screening is recommended. This is also a prerequisite for potential future repatriations and reintroductions. For instance, recent genetic analyses have confirmed that several if not all captive groups of *Bedotia* previously designated as *B. geayi* in fact are *B. madagascariensis* (Ziegler et al., 2020), and *B. geayi* should, therefore, be included in the list of threatened species which are (probably) not yet represented in ex situ holdings (Table 8).

To optimize management and conservation efforts, refocusing on threatened species may also be useful in some cases, and fish stocks reviewed accordingly. For example, the nonthreatened *Ptychochromis grandidieri* is highly represented in European captive holdings, and keeping instead one of the threatened species might be advisable at least in some cases. Recommendations are given in Table 8. However, circumstances can change quickly and should be considered as well. For example, *Ptychochromis insolitus* was among the rarest fishes only few years ago. Only through the recent buildup of a conservation breeding network (Ziegler et al., 2020), the species is no longer listed with top priority in Table 8—which it would have had deserved only few years ago.

Of the 19 threatened endemic Malagasy freshwater fish species kept in zoos worldwide, nine species (with *Bedotia geayi* in zoos treated as *B. madagascariensis*) have reproduced recently. Certainly, the success of captive breeding can be improved through better exchange of individuals and information, optimized transfers, and a focus on species that did not yet reproduce. This also should involve private breeders which can be key to a successful conservation breeding program. For instance, the Cologne Zoo received offspring of the rarely kept *Ptychochromis oligacanthus* from a private breeder recently, and they have already begun to reproduce. The aplocheilid *Pachypanchax sparksorum*, and the cichlids *Paretroplus dambabe* and *P. nourissati* are currently held only by private keepers. Here, zoo-based conservation breeding programs of these threatened species should be established based on private surplus (Table 8).

In turn, zoos can and should get involved in transferring offspring to specialized private breeders and include these in the conservation breeding network. Recently, the initiative Citizen Conservation (CC), which involves dedicated private keepers (www.citizen-conservation.org) has launched a breeding program starting, e.g., with *Ptychochromis insolitus* and *P. loisellei*, with plans to include even more threatened Malagasy freshwater fishes in the near future. This exemplifies the potential for a powerful synergy between zoos and private holders in ex situ conservation of small-sized vertebrate species. Increasing number of holdings in Table 8 thus also implies CC facilities.

As previously mentioned, field research in Madagascar must continue to uncover overlooked freshwater fish diversity before it is lost. This should also be increasingly tied to conservation breeding efforts, as it is crucial to legally allow the capture and transfer of threatened taxa to set up ex situ populations of species not yet kept in captivity. Ideally, the strategy should include ex situ holdings in Madagascar, such as a domestic freshwater fish breeding facility in Andapa managed by Association des Producteur Privés d'Alevins (APPA). However, distributing insurance populations also among various institutions abroad continue being essential to be better prepared for catastrophic events affecting the local facilities.

TABLE 8 Topical recommendations for improved conservation breeding network for Malagasy freshwater fish species currently listed as threatened by IUCN (2020); Ziegler et al. (2020) recommended *Gogo atratus* and *Ptychochromis ernstmagnusi* to be upgraded from DD to VU, and then they would have to be added to the list under the category "establish ex situ population" with xxx and x; as DD species *Gogo brevibarbis* and *Ptychochromis makira* are not included, but as micro-endemic species ex situ populations should likewise be established for; them according to Ziegler et al. (2020), *Sauvagella robusta* may move from EN to LC

Threatened endemics (IUCN status)	Establish ex situ population	Increase number of holdings	Transfer surplus from hobbyist to zoo	Husbandry
Anchariidae				
Ancharius griseus (EN)	xx			
Gogo ornatus (EN)	xx			
Aplocheilidae				
Pachypanchax arnoulti (VU)		xxx		Zoo expertise
P. omalonotus (EN)		xx		Sterba (1990), Mailliet (2006), private and zoo expertise
P. patriciae (EN)		xxx		zoo expertise
P. sakaramyi (EN)		x		Schäfer (2018), Ziegler et al. (2020), private and zoo expertise
P. sparksorum (EN)			xxx	Private expertise
P. varatraza (EN)		xxx		Private and zoo expertise
Ariidae				
Arius festinus (CR)	xxx			
A. uncinatus (CR)^{MiEnd}	xxx			
Atherinidae				
Teramulus waterloti (EN)	xx			
Bedotiidae				
Bedotia albomarginata (EN)	xx			(see Mailliet, 2004)
B. geayi (EN)^{MiEnd}	xxx			(see Mailliet, 2004; Ziegler et al., 2020), zoo expertise
B. leucopteron (EN)^{MiEnd}	xx			(see Mailliet, 2004)
B. longianalis (EN)		xxx		Mailliet (2004), zoo expertise
B. madagascariensis (EN)^{stable}				Mailliet (2004), Ziegler et al. (2020), private and zoo expertise
B. marojejy (EN)		xxx		Mailliet (2004), zoo expertise
B. masoala (VU)^{MiEnd}	xxx			(see Mailliet, 2004)
B. tricolor (CR)	xxx			(see Mailliet, 2004)
Rheocles alaotrensis (EN)	xx			
R. derhami (CR)^{MiEnd}	xxx			
R. lateralis (CR)^{MiEnd}	xxx			
R. vatosoa (EN)^{MiEnd}		xxx		Ziegler et al. (2020), zoo expertise
R. wrightae (EN)	xx			
Cichlidae				
Katria katria (EN)	xx			
Oxylapia polli (EN)^{MiEnd}	xxx			

(Continues)

TABLE 8 (Continued)

Threatened endemics (IUCN status)	Establish ex situ population	Increase number of holdings	Transfer surplus from hobbyist to zoo	Husbandry
Paratilapia polleni (VU)[stable]				Private and zoo expertise
Paretroplus dambabe (CR)[MiEnd]			xxx	Private expertise
P. damii (VU)		xx		Private and zoo expertise
P. gymnopreopercularis (CR)[MiEnd]	xxx			
P. kieneri (VU) [stable]				Private and zoo expertise
P. lamenabe (EN)	xx			
P. loisellei (EN)		xxx		Zoo expertise
P. maculatus (CR)		xxx		Albering (2002), private and zoo expertise
P. maromandia (EN)	xx			
P. menarambo (CR)[MiEnd]		xx		Albering (2002), private and zoo expertise
P. nourissati (EN)[ReEnd]			xxx	Private expertise
P. tsimoly (EN)	xx			
Ptychochromis inornatus (EN)	xx			(see Albering, 2013)
P. insolitus (CR)[MiEnd]		xx		Albering (2013), Ziegler et al. (2020), zoo expertise
P. loisellei (EN)[MiEnd]		xx		Albering (2013), Ziegler et al. (2020), zoo expertise
P. oligacanthus (EN)		xx		Albering (2013), private and zoo expertise
Ptychochromoides betsileanus (CR)	xxx			
P. itasy (CR)	xxx			
P. vondrozo (EN)	xx			
Clupeidae				
Sauvagella robusta (EN)	x			
Kuhliidae				
Kuhlia sauvagii (VU)	x			
Milyeringidae				
Typhleotris madagascariensis (EN)[ReEnd]	xxx			
Typhleotris mararybe (CR)[ReEnd]	xxx			
T. pauliani (CR)[ReEnd]	xxx			

Note: MiEnd =micro-endemic, ReEnd = regional-endemic; Stab = stable ex situ population at time; xxx = most urgent.

Abbreviations: CR, critically endangered; DD, data deficient; EN, endangered; EX, extinct; LC, least concern; NE, not evaluated; NT, near threatened; VU, vulnerable.

Together such a strategy complies with the One Plan Approach proposed by the IUCN SSC Conservation Breeding Specialist Group (CBSG), viz. the development of management strategies and conservation actions by all responsible parties for all populations of a species, whether inside or outside their natural range. As exemplified by the multidisciplinary approach by Fish Net Madagascar (https://fishnetmadagascar.com/), any strategy must consider that in the long term ex situ measures can only prove successful in concert with a perspective for in situ conservation actions to restore and long-term protect a species' natural habitat.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

ETHICS STATEMENT

The protocol and procedures employed were ethically reviewed and approved by Cologne Zoo's director and the Madagascar Fauna and Flora Group.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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